Avoid the Unmanageable, Manage the Unavoidable

What can we expect from the climate in the coming decades, and what can we do?

J. H. Plumb Auditorium, Christ's College, Thursdays, 5:30 to 7 pm

Charles F. Kennel

Director, Vice-Chancellor, and Distinguished Professor Emeritus,
Scripps Institution of Oceanography,
University of California, San Diego

Distinguished Visiting Fellow,
Christ's College, Cambridge

Visiting Research Fellow,
Centre for Science and Policy
University of Cambridge

Feb 13, 2014: Sea Level Rise, Coastal Cities, and Wetlands

- Factors affecting rates of global and local sea level rise
- How advanced regions are preparing-Venice, the Netherlands, Sacramento Bay-Delta
- Vulnerable cities, agricultural river deltas, low-lying island nations

Adaptation

Assess, Decide, Act

Think Globally, Assess Regionally, Act Locally

Ice, Snow, and Water

Kennel, C.F., "Think Globally, Assess Regionally, Act Locally",
Issues in Science in Technology,
***25, 2,* 46-52, 2009, National Academies, ISSN: 0748-5492**

Ice, Snow, and Water

Impacts of Climate Change on California and Himalayan Asia
May 4-6, 2009, La Jolla
Jammu and Kashmir, October 2009

Mountain Cryospheric Reservoirs - A link between climate and water availability for societies and natural systems
Aug 30-31, 2010, Potsdam

Fate of Mountain Glaciers in the Anthropocene
Casina Pio IV, Vatican Academy of Sciences
April 2-4, 2011

Improving the capacity to assess and to adapt to climate change in urban coastal regions
The Venice Conference,
September 12-15, 2011

Impacts of Climate Change on California and Himalayan Asia

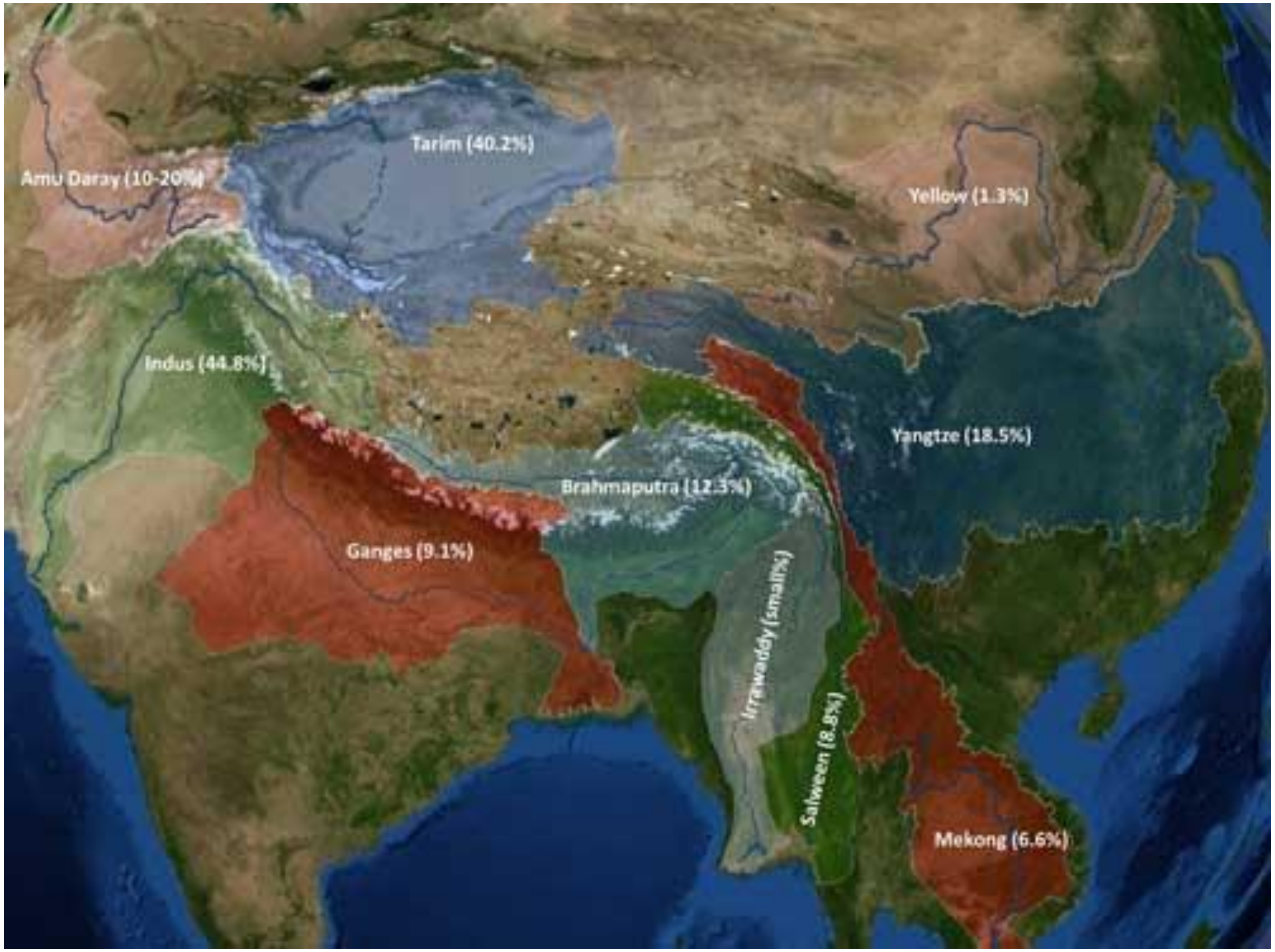
Far away from melting snows and glacial lake outbursts

Scripps Institution of Oceanography, La Jolla, May 4-6, 2009

Third largest cryospheric reservoir

11 largest rivers in Asia have headwaters in the Himalaya-Hindu Kush

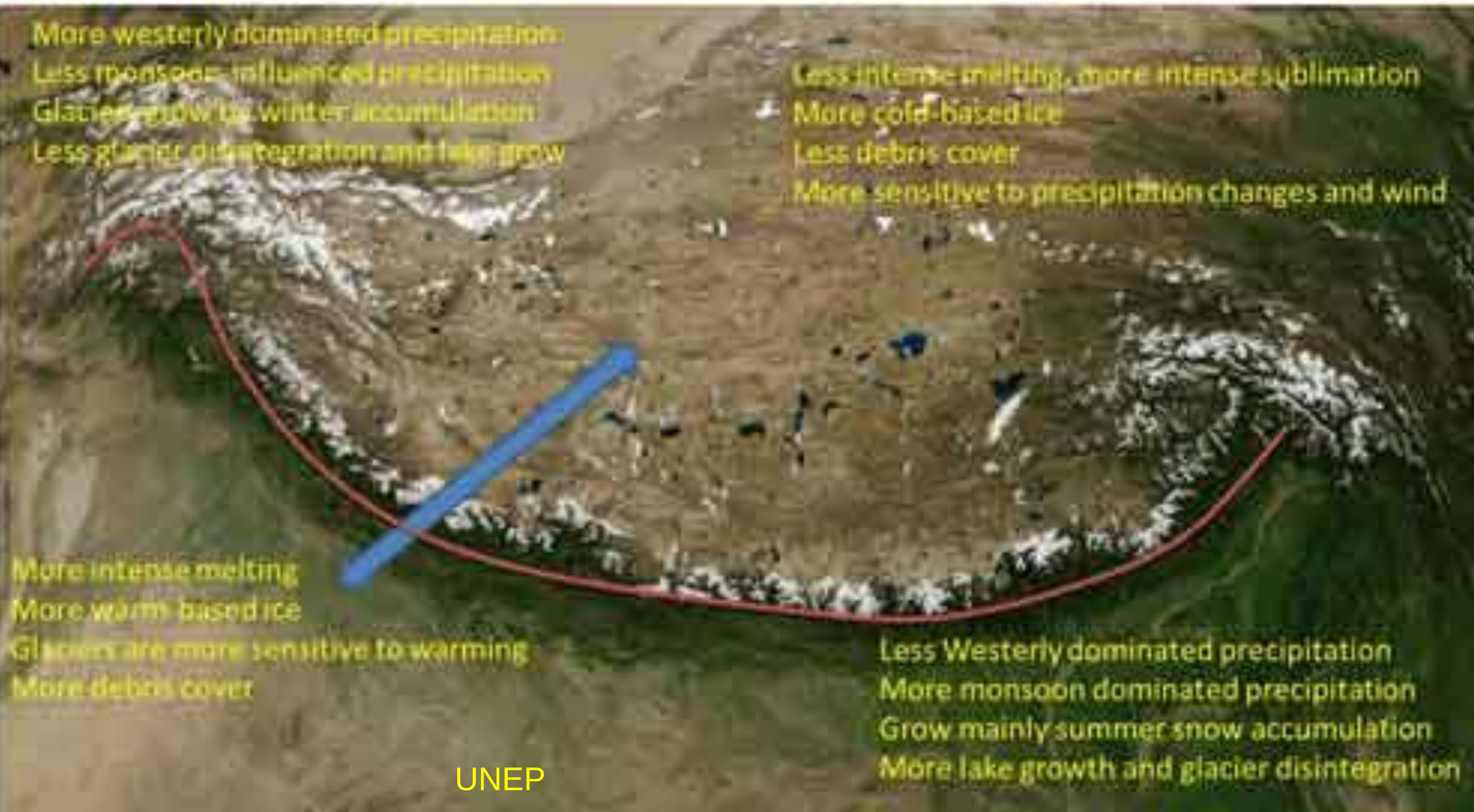
Percentages of Seasonal Snow and Ice Melt To Annual River Flows



The Indus is the most vulnerable to glacier and snow melt
70% of its water is diverted for agricultural irrigation
UNEP

Prevailing Himalayan Weather Patterns

River flow depends on both upstream and downstream weather
Each basin's headwater region has its own meteorology



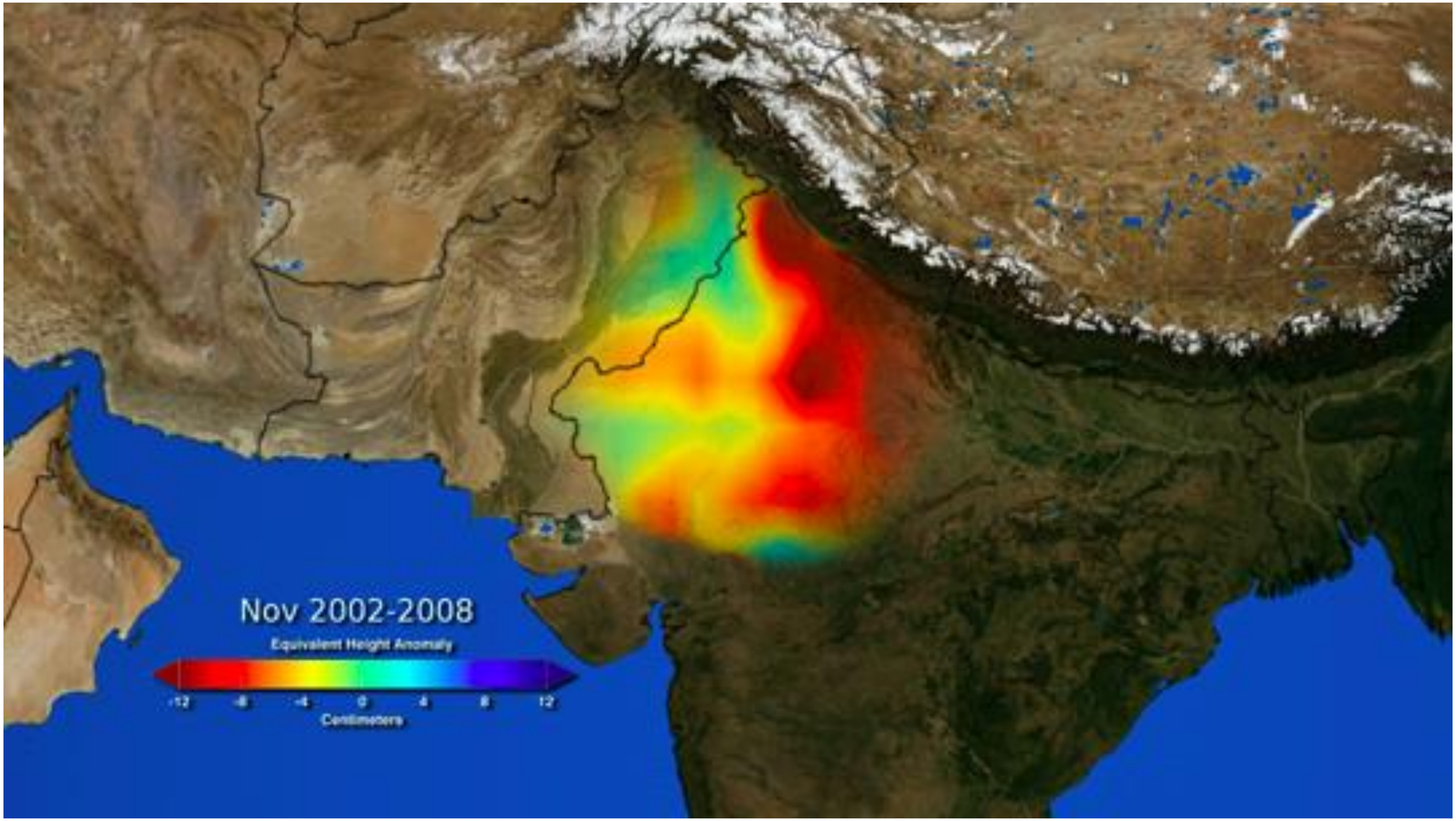
The Ganges Challenge

Integrated River Assessment

How does changing climate affect Gangotri snows and glaciers?
What are the impacts of black carbon on snowmelt and the monsoon?
How much Ganges water comes from mountains, monsoon, and underground?
What is the impact of the large withdrawals from the sub-Ganges aquifer?
Why is the monsoon becoming more variable, and what can we expect?
How do changing temperature, water, monsoon, and black carbon affect agricultural productivity and food security?

Unsustainable Water Withdrawal

Gangetic Plain



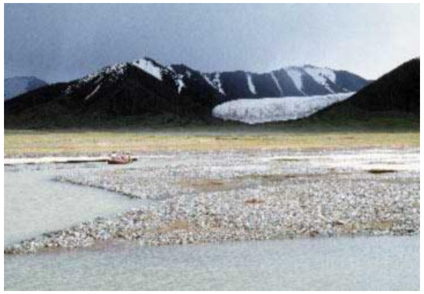
NASA *Grace* Satellites

Quintessential Natural System Assessment

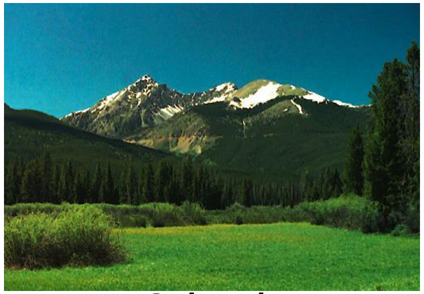
Ice, Snow, and Rivers

The social impacts of climate change on mountain-fed river systems

Ganges



Yangtze



Colorado

Amazon

Every river passes through different landscapes and micro-climates, and by societies with different structures, needs, and ways of reaching decisions.

How will population and water demand evolve in the "social catchments" of each river basin?

How does climate change factor into other environmental and socio-economic issues?

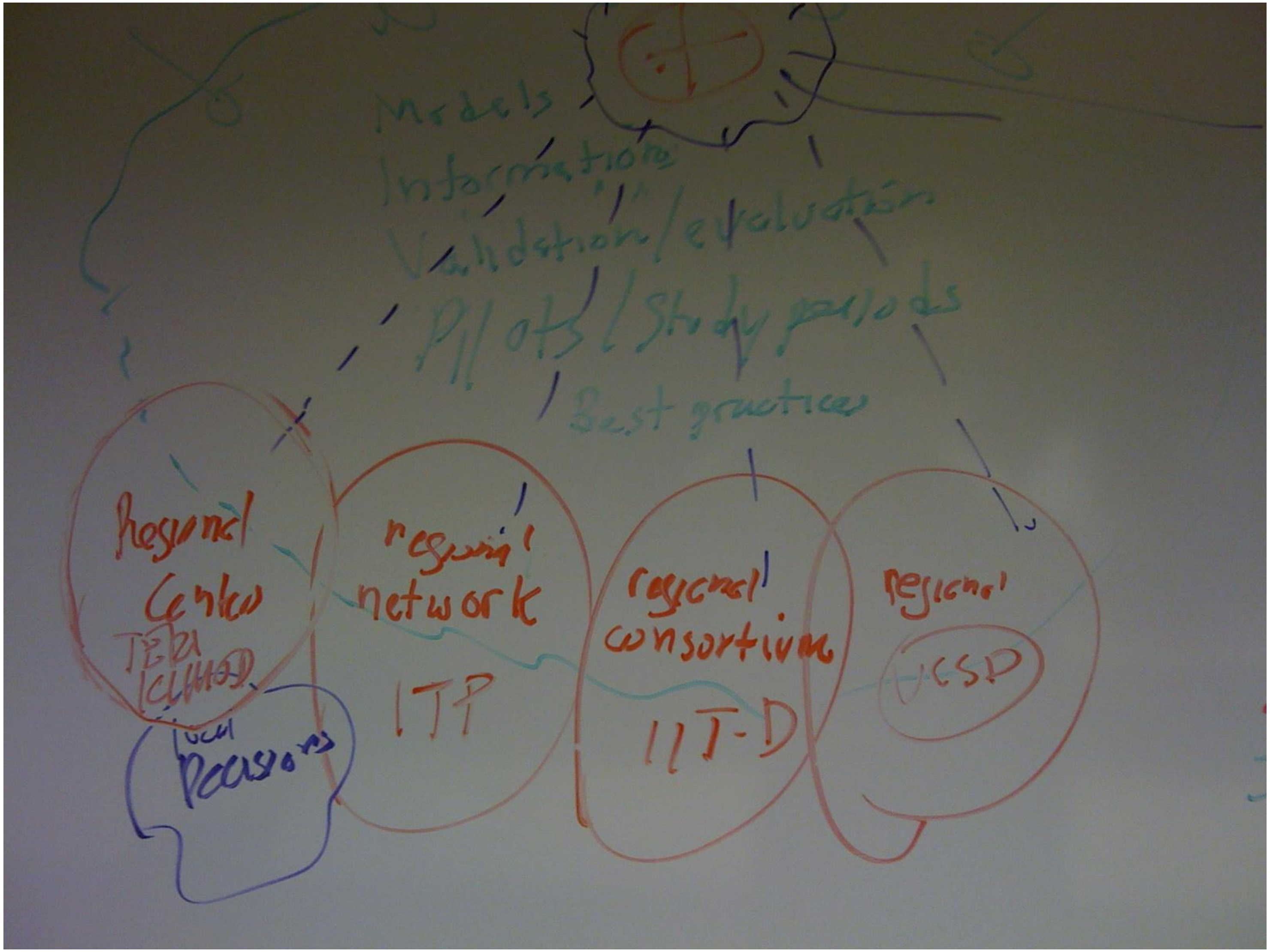
How much time does each region have to develop adaptive responses?

Who makes water management decisions?

What is required for decision makers to respond to an assessment?

Improving the Capacity to Assess

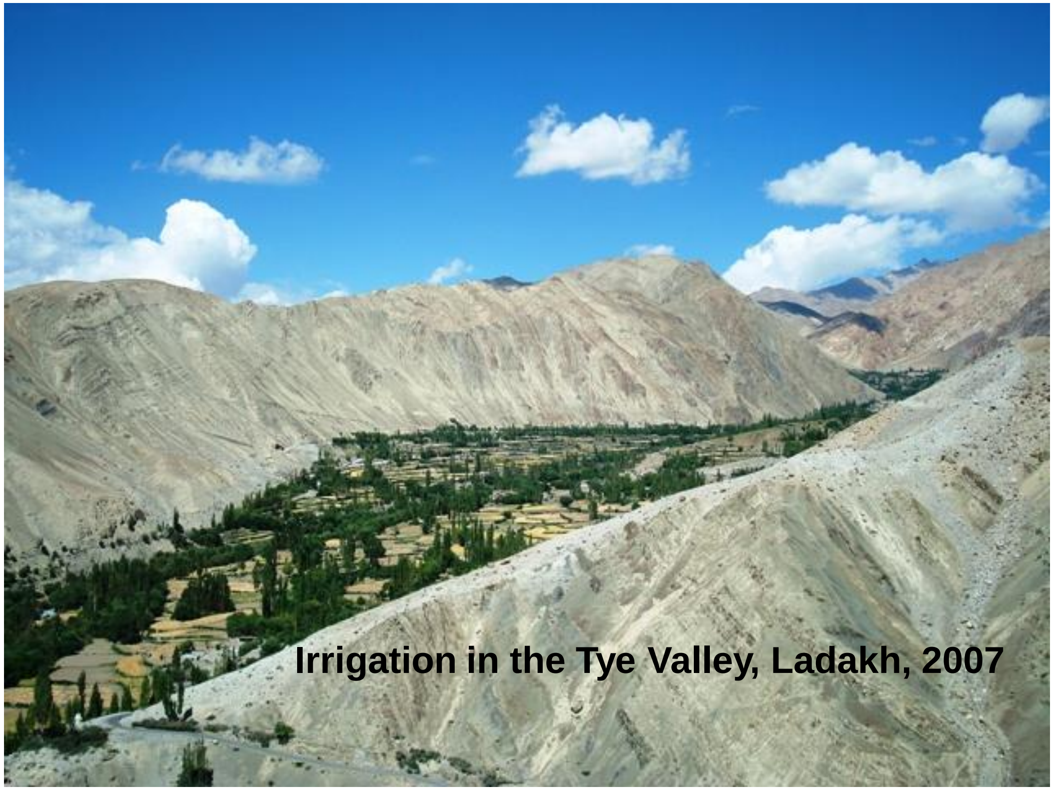
Valedictory Thoughts, May 7, 2009



Cambridge: Sally Daultrey, Dick Fenner, Julian Hunt, Grant Kopec
Melbourne: Jim Falk; UCSD: Mike Dettinger, Charlie Kennel, Paul Linden, Kim Mcintyre

Jammu and Kashmir

In collaboration with the Cambridge-UCSD Global Water Initiative, October 2009
The first international workshop of its kind to be held in J&K
120+ participants from Glaciology. Hydrology. Social Sciences and Government


Irrigation in the Tye Valley, Ladakh, 2007

"As a storehouse for water and biological diversity, the Himalayan region holds the key to India's ecological and social security. Assessing the state of the natural systems is the starting point for determining the effects of environmental change on society (especially on agriculture, livelihoods and human health) and for understanding the connections between environmental and social change."

Mountain Cryospheric Reservoirs And River Flow

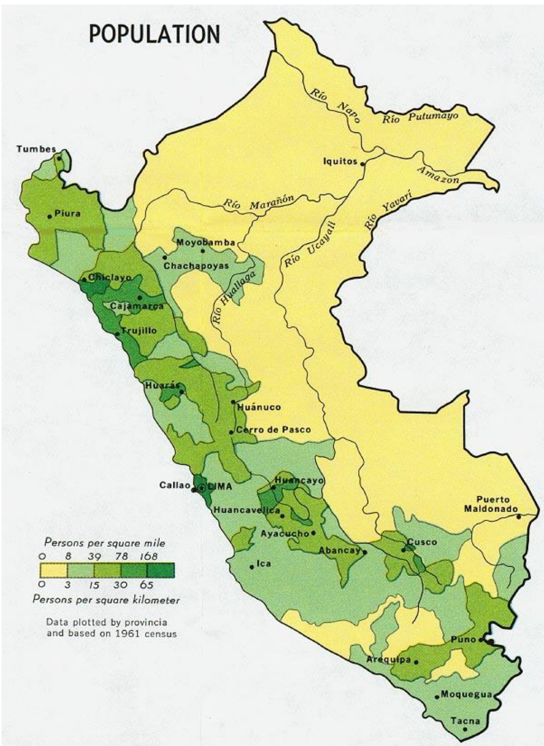
What must be synthesized to assess the things decision-makers care about

- **Space observations of snow area**
- ***In Situ* measurements of depth, crystal size, and snow-water equivalent**
- **Cloudiness/insolation, topography, black carbon deposition on snow**
- **Fraction of melt-water diverted underground, storage times**
- **River basin precipitation and evaporation, human withdrawals**
- **Statistics of large storms, which account for most snow deposition**
- **Sediment transport-important to agriculture-occurs in extreme flooding events**

Coastal Peru Desert

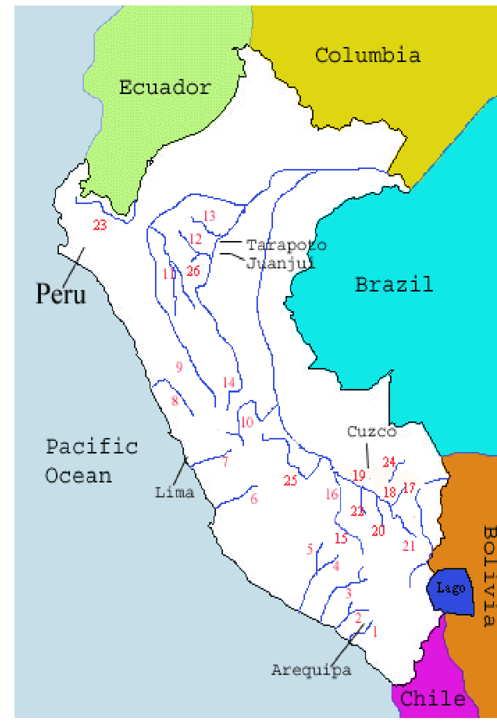
Almost Completely Dependent on Andean Water

Rainforest east of the Andes, desert to the west
Towns and indigenous villages alike at risk



Population

Rainfall



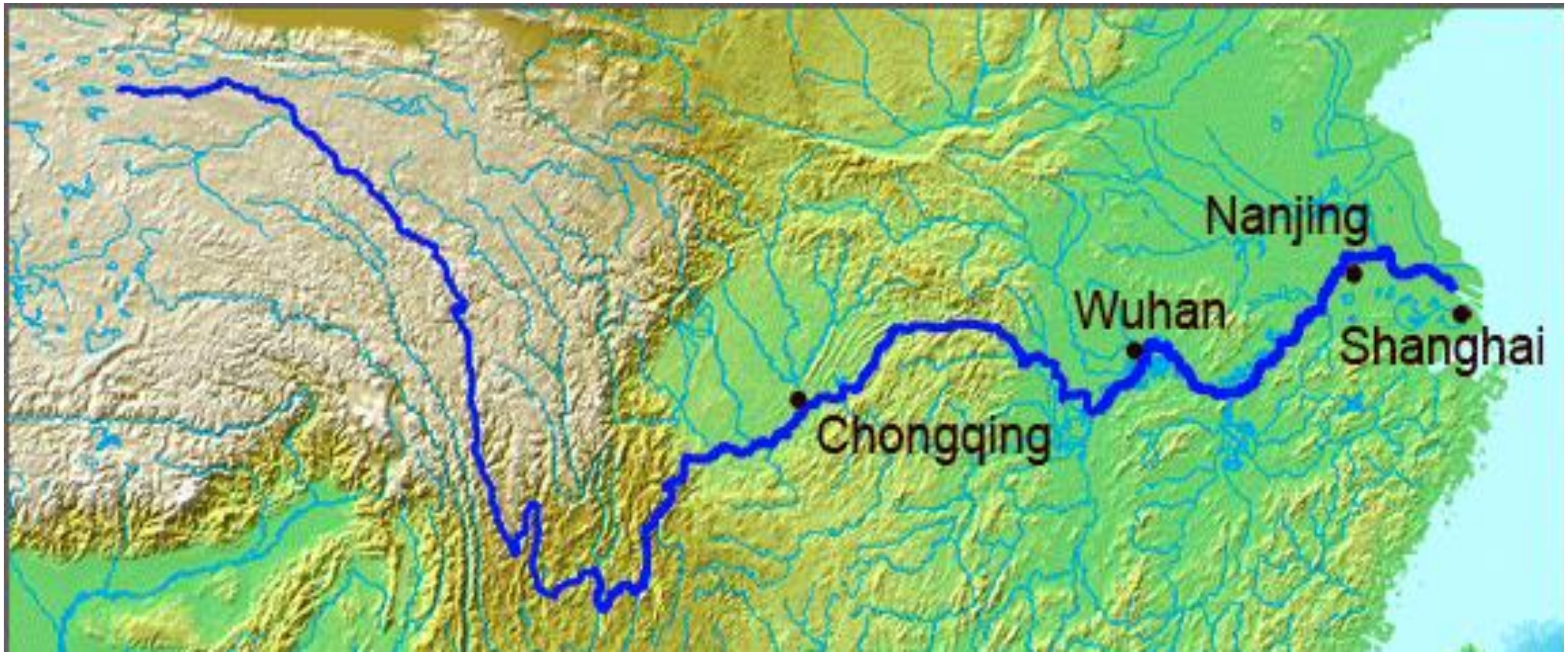
Major Rivers

Mountain Cryospheric Reservoirs -
A link between climate and water availability for societies and natural systems
Aug 30-31, 2010, Potsdam

The Yangtze

The most important river in the world

Avatar of China's Environmental Destiny
Global Geophysical and Geopolitical Importance



The Yangtze, the largest Himalayan region river by discharge, originates in the mountains of Quinghai province on the Tibetan Plateau and flows 6300 km south and west to meet the East China Sea at Shanghai. Its river basin is estimated to account for 40% of China's fresh water resources, more than 70% of rice and fishery production, and 20-40 % of China's GDP. A vast project to divert 1/3 of its flow northward is under way, despite prolonged drought, and times when it has run dry.

Thanks to Josh Graff-Zivin, UCSD

Climate Change and the Yangtze

An end-to-end assessment

Richard Carson, Economics, Josh Graff-Zivin, International Relations and Pacific Studies,
Charlie Kennel, Scripps, Hildegard Diemberger, Department of Social Anthropology, Cambridge, …




Natural Science

1. Overview of the Issues
2. Physical Geography of the Yangtze Basin
3. Socioeconomic Geography of the Yangtze Basin
4. Downscaling Climate Impacts to the Basin Level
5. Climate Induced Changes, 1: Temperature and Precipitation in the Yangtze Basin
6. Climate Induced Changes, 2: Glaciers and Water Flows on the Tibetan Plateau
7. Climate Induced Changes, 3: New Hydrological Regimes for the Yangtze
8. Options for responding to Climate Induced Changes in the Yangtze's Hydrology

Social Science

9. International and Security Implications
10. Feasibility of Infrastructure Investments to Address Increased and Decreased Yangtze Water Flows
11. Ecosystem Impacts of Changes in Yangtze's Water Flows with/without Infrastructure Investments
12. Economic Impacts of Options for Responding to Climate Induced Changes in Yangtze's Hydrology
13. Impact of Changing Hydrology on Water Pollution
14. Social Impacts of Options for Responding to Climate Induced Changes in Yangtze's Hydrology
15. Conclusions and the Way Forward

Fate of Mountain Glaciers in the Anthropocene

A World-Wide View

Casina Pio IV, Vatican Academy of Sciences, April 2-4, 2011

Already, when warming has been only 0.8 degC,

"Glaciers are shrinking in area worldwide, with the highest rates documented at lower elevations. The widespread loss of glaciers, ice, and snow on the mountains of tropical, temperate, and polar regions is some of the clearest evidence we have for a change in the climate system…",

Rongbuk Glacier, North Face, Mount Everest

Fate of Mountain Glaciers in the Anthropocene, **Pontifical Academy of Sciences, 2011**

Retreat a Relic of Little Ice Age?

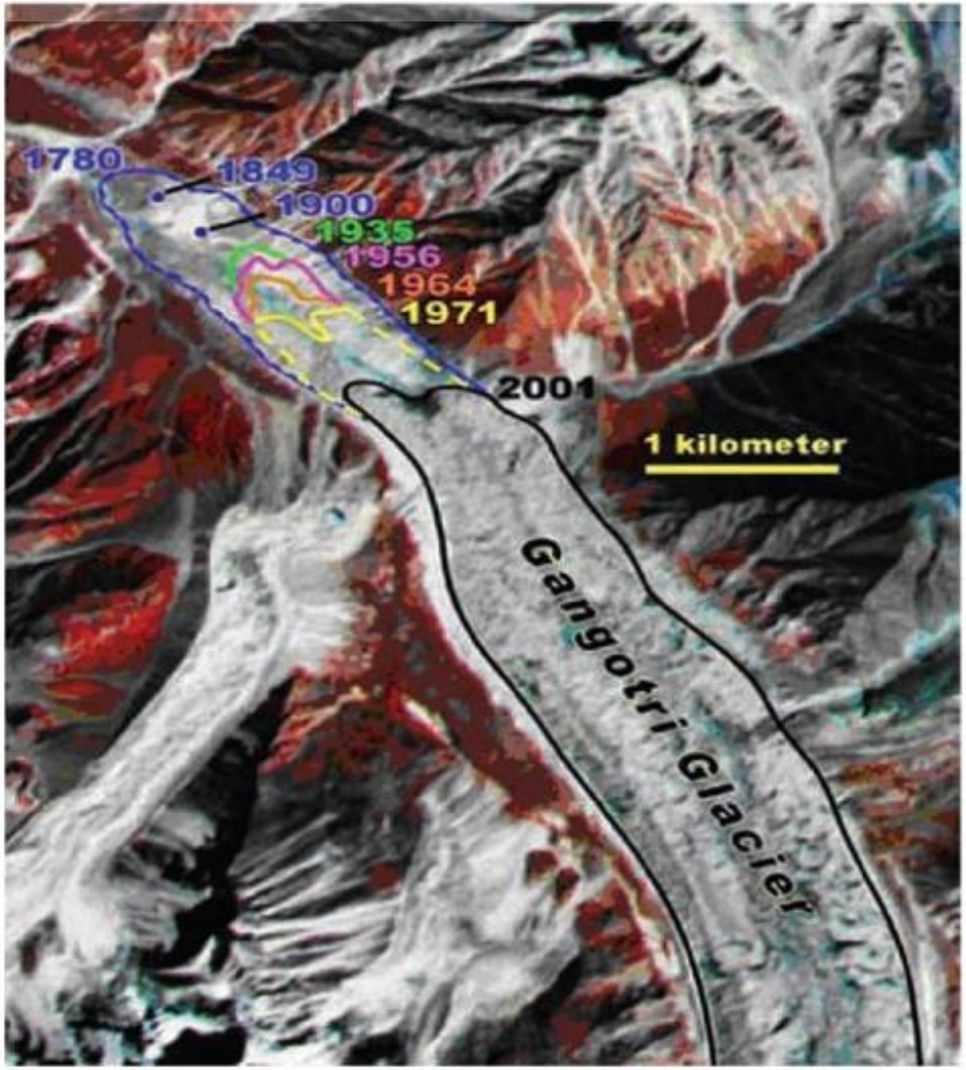


Figure 10.6. *Composite satellite image showing how the Gangotri Glacier terminus has retracted since 1780 (courtesy of NASA EROS Data Center, 9 September 2001).*

Courtesy, Georg Kaser

Mt. Kilimanjaro, Tanzania

1912-1953, 1%/yr
1989-2005, 2.5%/yr

Recent changes unprecedented in an 11,700 year reord

L. G. Thompson, H. H. Brecher E. Mosley-Thompson, D. R. Hardy and B. G. Mark, Glacier loss on Kilimanjaro continues unabated, PNAS, 106, 47, 19770, 2009; doi: 10.1073/pnas.0906029106

Attribution the Preoccupying Technical Issue

150-year Swiss records the only ones to distinguish between more rapid retreat from recent warming and slower recovery from little ice age

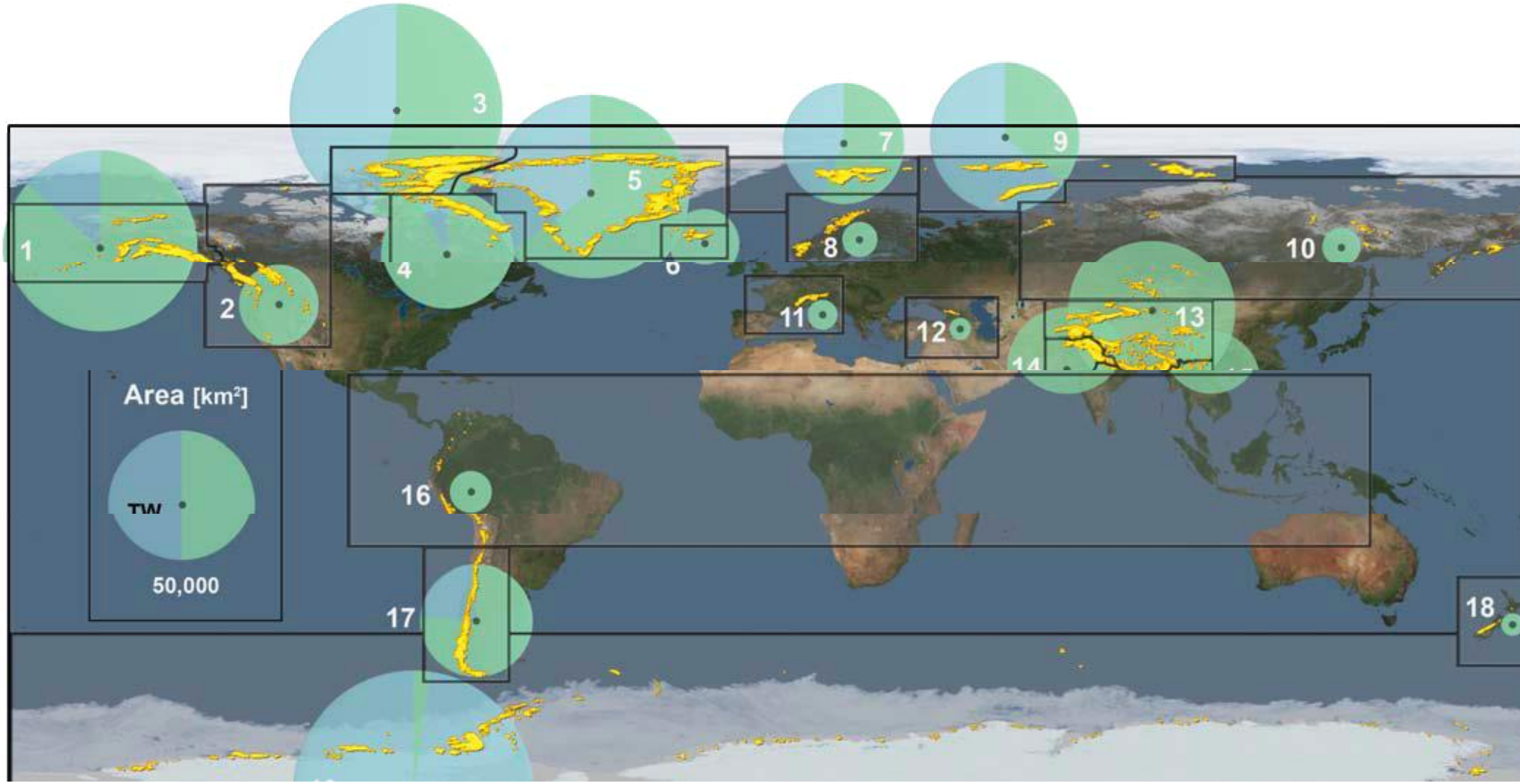
Morteratsch Glacier (Alps)

Fate of Mountain Glaciers in the Anthropocene

Casina Pio IV, Vatican Academy of Sciences, April 2-4, 2011

A Nearly Complete Global Glacier Inventory

Only 42% complete in AR4

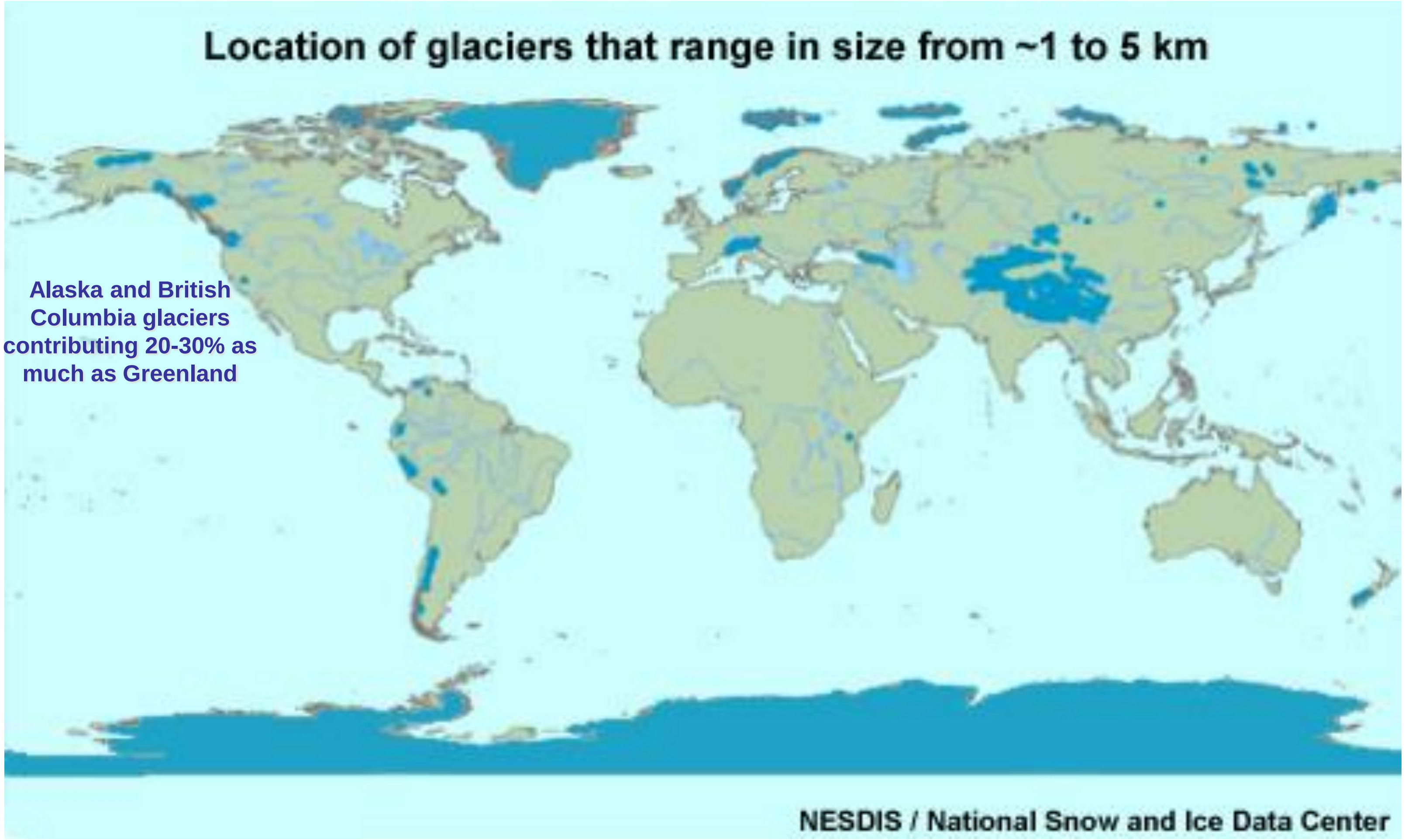


Glaciers (exaggerated in size) in yellow, ice area given by diameter of circle, percentage area in tidewater coloured green

Arendt, A., et al., 2012: Randolph Glacier Inventory [v2.0]: A Dataset of Global Glacier Outlines. 1-32 pp.
Gardner, A. S., et al., 2013: A Consensus Estimate of Glacier Contributions to Sea Level Rise: 2003 to 2009, in press..

Mountain Glacier Mass Loss

"The average rate of ice loss from glaciers around the world, *excluding glaciers on the periphery of the ice sheets*, was very likely 226 [91 to 361] Gt yr−1 over the period 1971 to 2009, and very likely 275 [140 to 410] Gt yr−1 over the period 1993 to 2009." IPCC AR5



Jacob, T., J., *et. al.*, *Nature*, 482, 514-518, 2012
Gardner, A. S., et al., 2011: Sharply increased mass loss from glaciers and ice caps in the Canadian Arctic Archipelago. *Nature*, 473, 357-360

Sea Level Rise

Historical

Projected

Global Sea Level-Past 20,000 years

As ice sheets retreated, sea level rose by about 120 m and then became relatively stable during present warm period

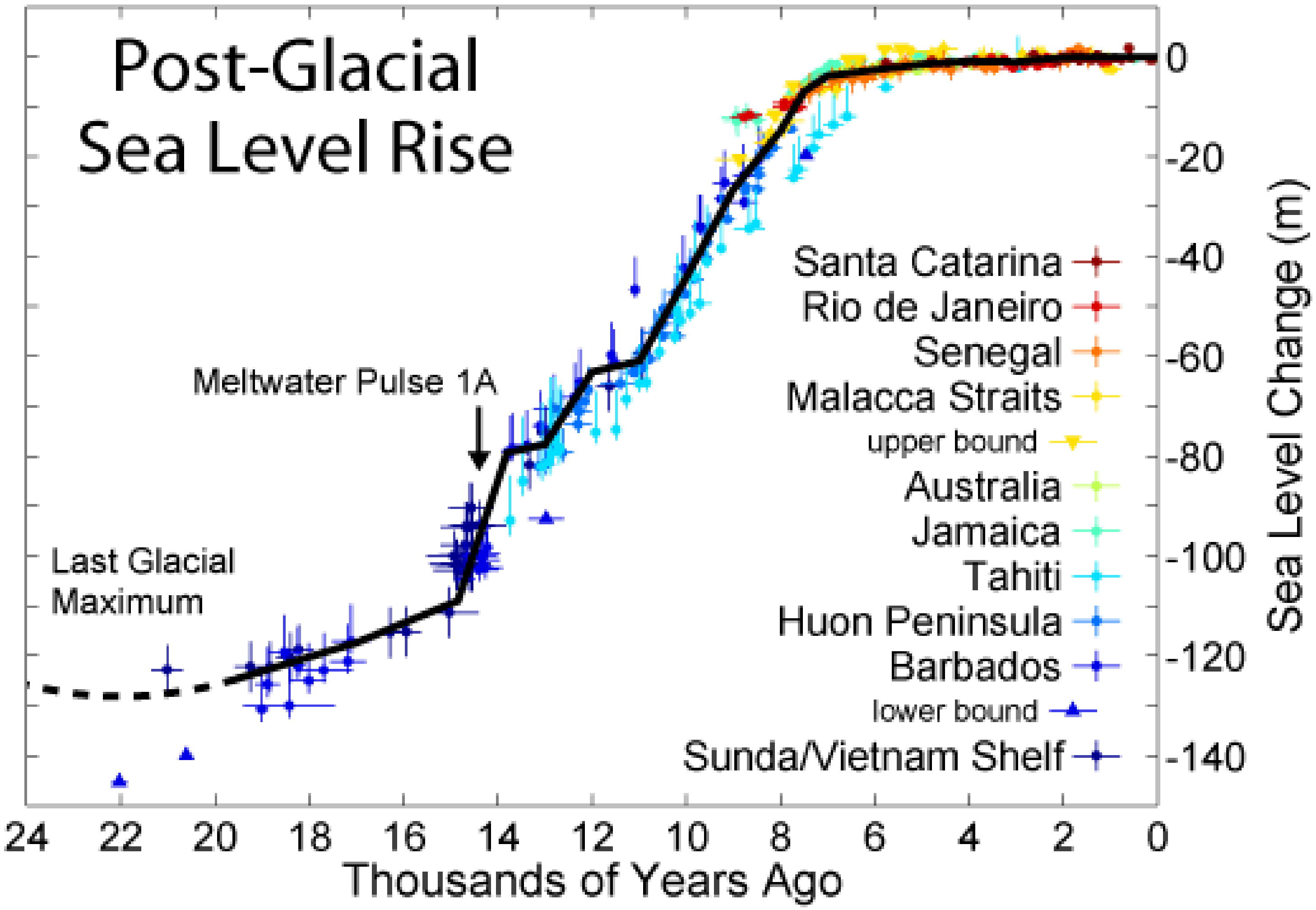
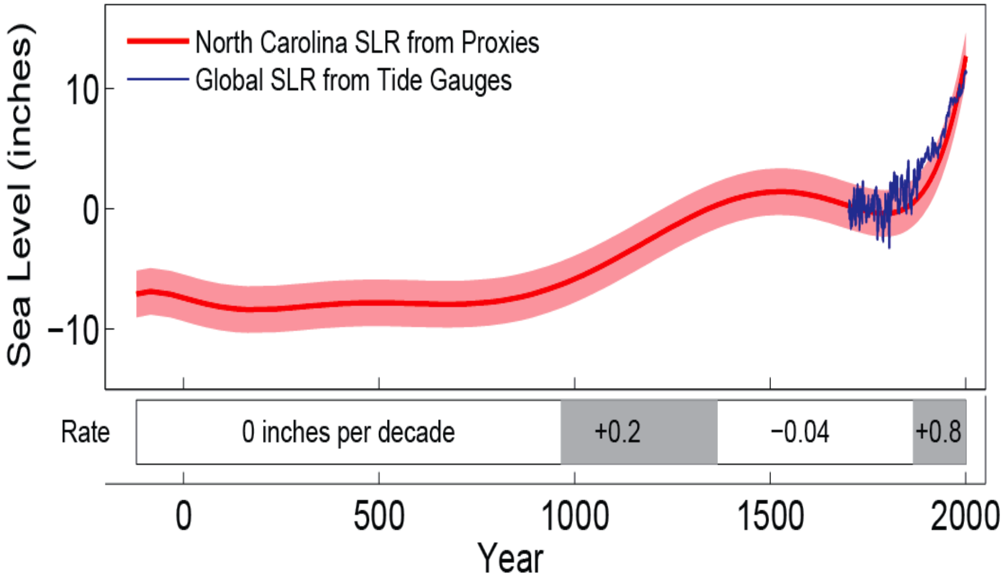


Image created by Robert A. Rohde / Global Warming Art

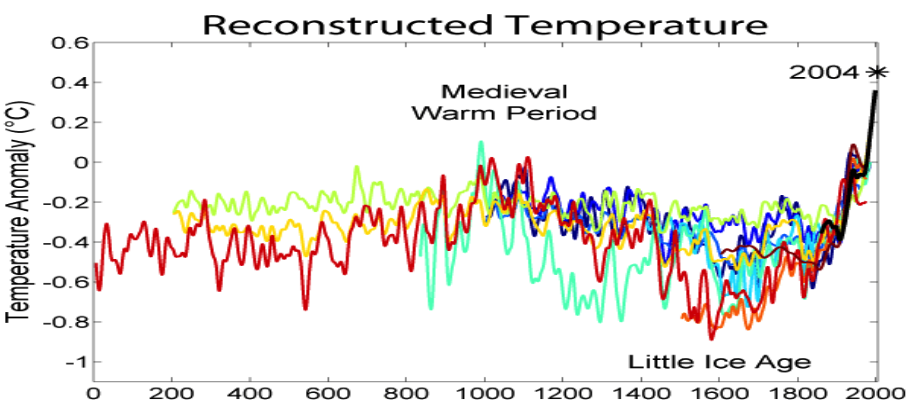
http://www.globalwarmingart.com/wiki/File:Post-Glacial_Sea_Level_png

Atlantic Sea Level-Past 2000 Years

Rise following Medieval Warm Period, Decline After Little Ice Age, Recent Increase



Rates of sea level change in the North Atlantic Ocean based on data collected from the U.S. East Coast (Kemp et al. 2012) (red line, pink band shows the uncertainty range) compared with a reconstruction of global sea level rise based on tide gauge data (Jevrejeva et al. 2008) (blue line). (Figure source: Josh Willis, NASA Jet Propulsion Laboratory)

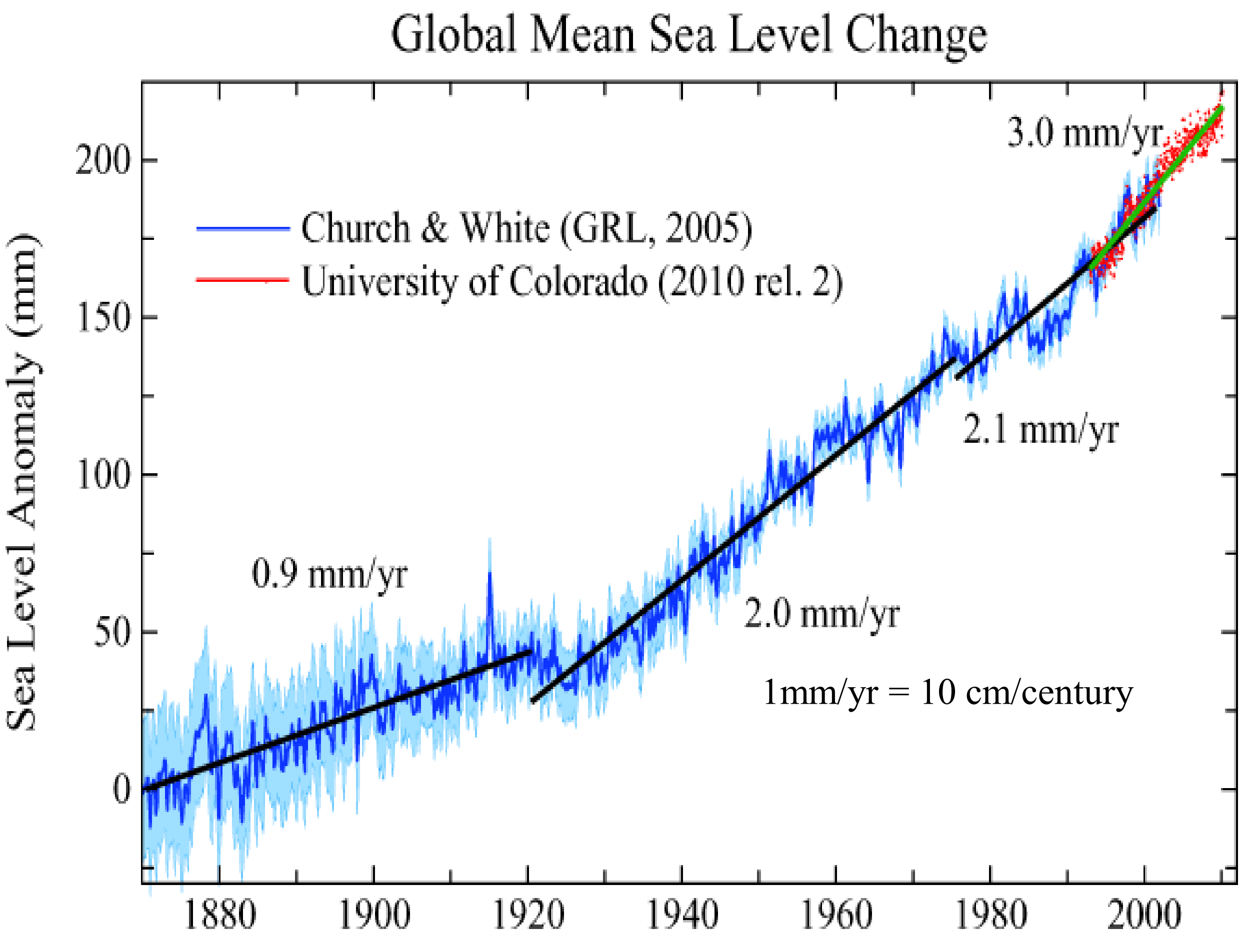


Comparison of 10 different published reconstructions of mean temperature changes during the last 2000 years. More recent reconstructions are plotted towards the front and in redder colors, older reconstructions appear towards the back and in bluer colors. An instrumental history is shown in black. (Wikipedia Commons)

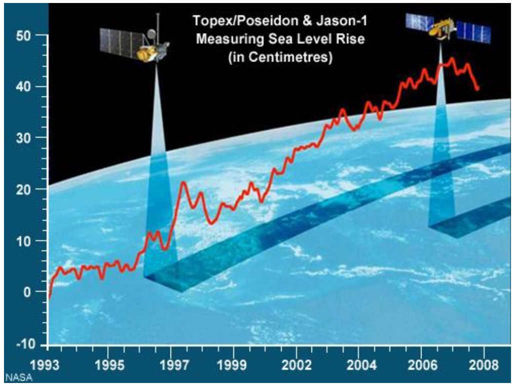
Global Sea Level-Past 150 years

Sea level rose throughout past century, accelerated in the last 20 years

Proxy and instrumental data indicate a transition in the late 19th and early 20th centuries from rate prevailing over past 2 millennia, AR5 2013



Satellite altimetry



Satellite Altimetry provides absolute measure of sea level referred to the center of gravity of the earth with mm precision

Projections of Global Mean Sea Level

IPCC AR4 2007 estimated a SLR between 18 and 59 cm for 2100 taking into account only the expansion of sea water with increasing temperature-the so-called steric effect. The expert group knew there are contributions from mountain glaciers, the Greenland and Antarctica Ice sheets, and underground reservoirs. It knew that the steric effect did not explain the observations of present sea level rise, but there was not enough agreement about the other sources to reach consensus. AR4 chose only to say that the steric estimate was a lower limit. While AR4 did say the true rate could be considerably larger, its steric estimate was the only "official" one.

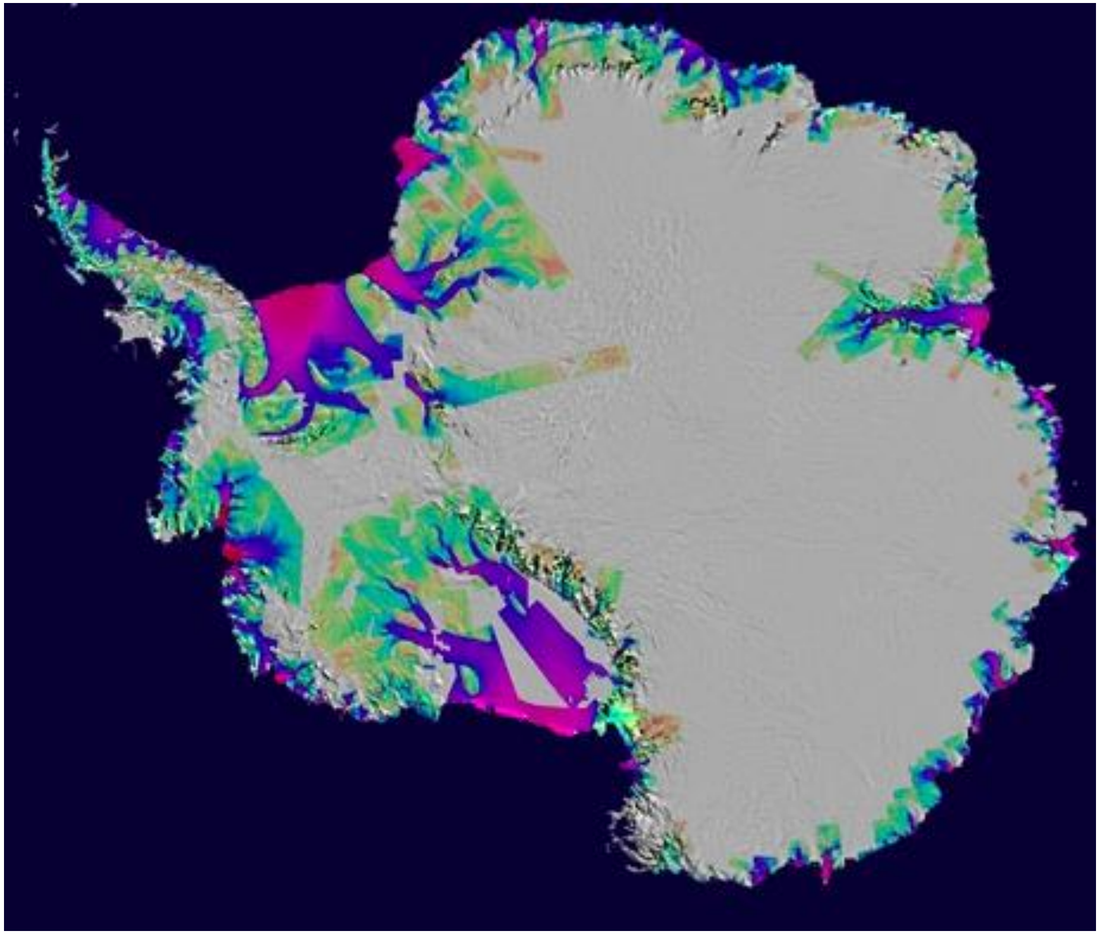
The engineering and policy communities planning for sea level rise may have been led to underestimate the challenges facing them. The seriousness of the problem was immediately recognized by the scientific community, and a veritable explosion of research followed. This is summarized in IPCC AR5 2013.

Stefan Rahmstorf, A Semi-Empirical Approach to Projecting Future Sea-Level Rise, Science 315, 368 (2007)

Nicholls, *et al, Phil. Trans R. Soc A, 369,* 161, 2011

Antarctic Ice Loss

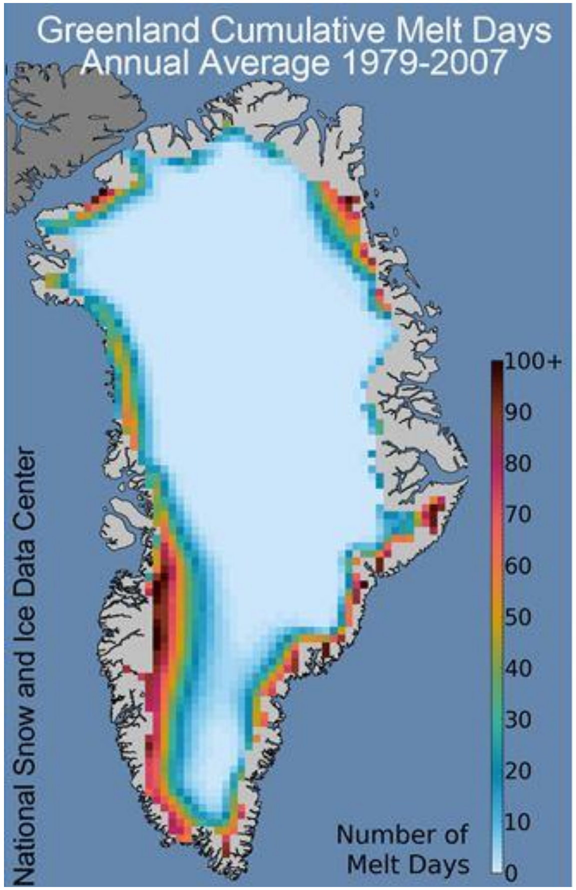
"The average rate of ice loss from the Antarctic ice sheet has likely increased from 30 [–37 to 97] Gt yr–1 over the period 1992–2001 to 147 [72 to 221] Gt yr–1 over the period 2002 to 2011" IPCC AR5, 2013

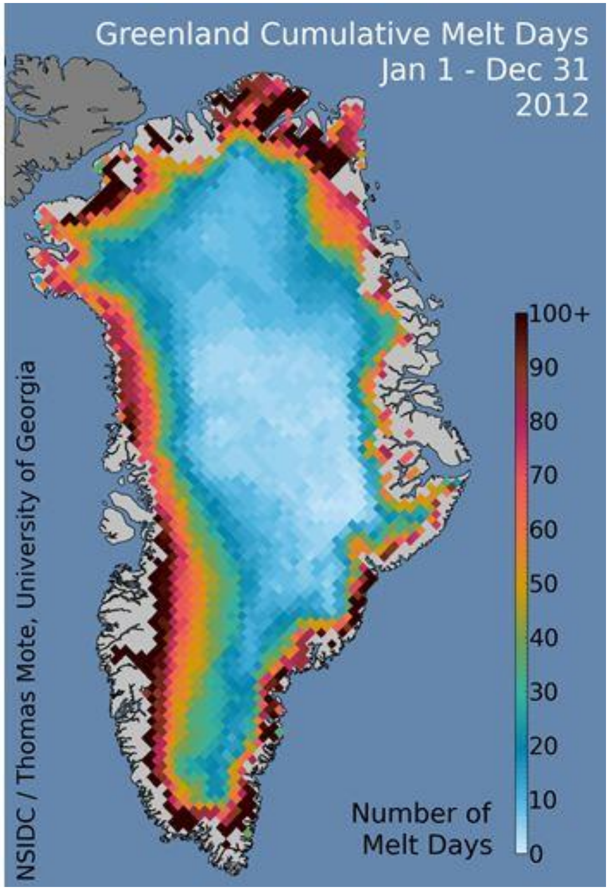


Regions of ice loss between 1996 and 2006 Rignot, *et.al., Nature Geoscience, 1*, 108, 2008

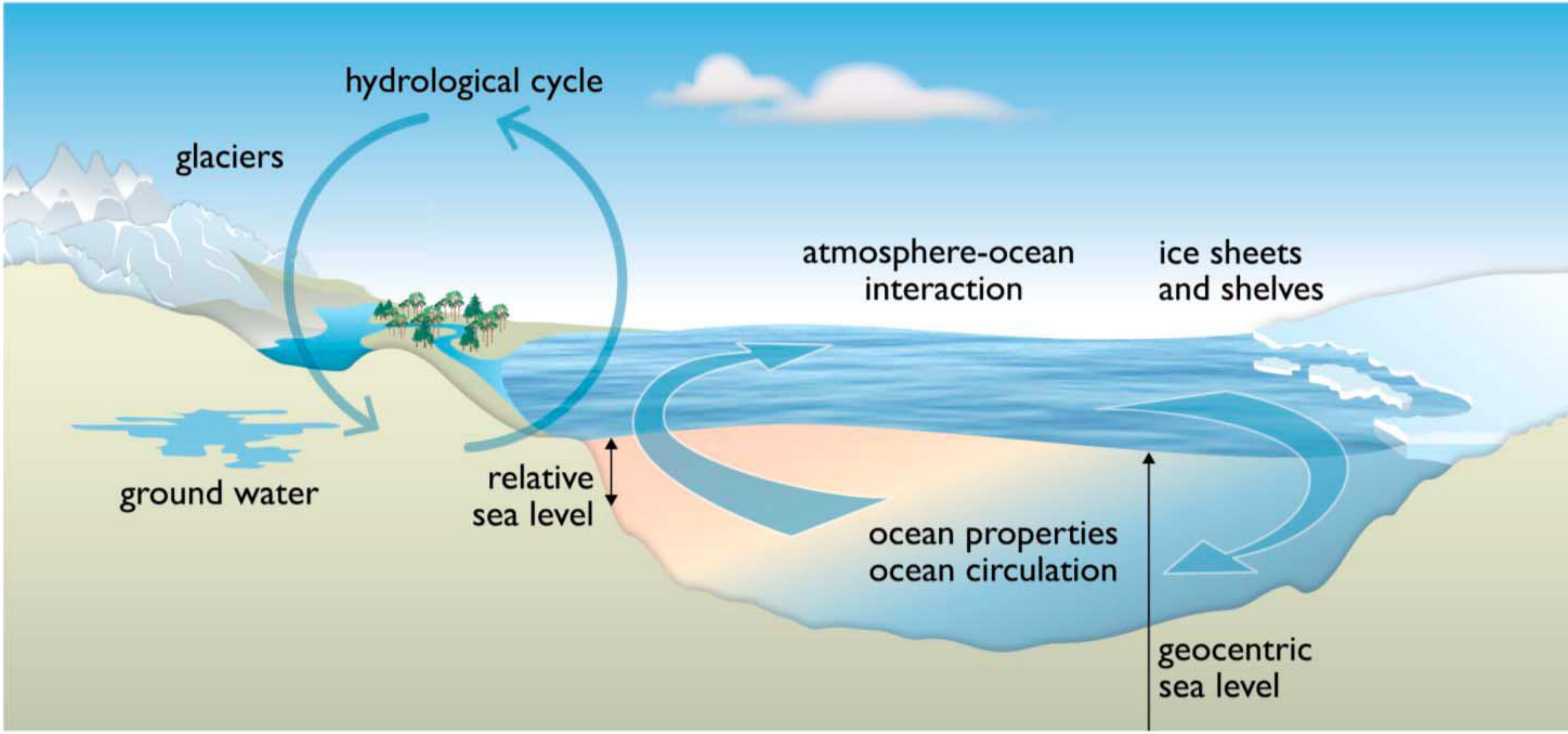
Greenland Ice Loss

"The average rate of ice loss from the Greenland ice sheet has very likely substantially increased from 34 [–6 to 74] Gt yr–1 over the period 1992 to 2001 to 215 [157 to 274] Gt yr–1 over the period 2002 to 2011. " IPCC AR5





Closure of the Sea Level Rise Budget

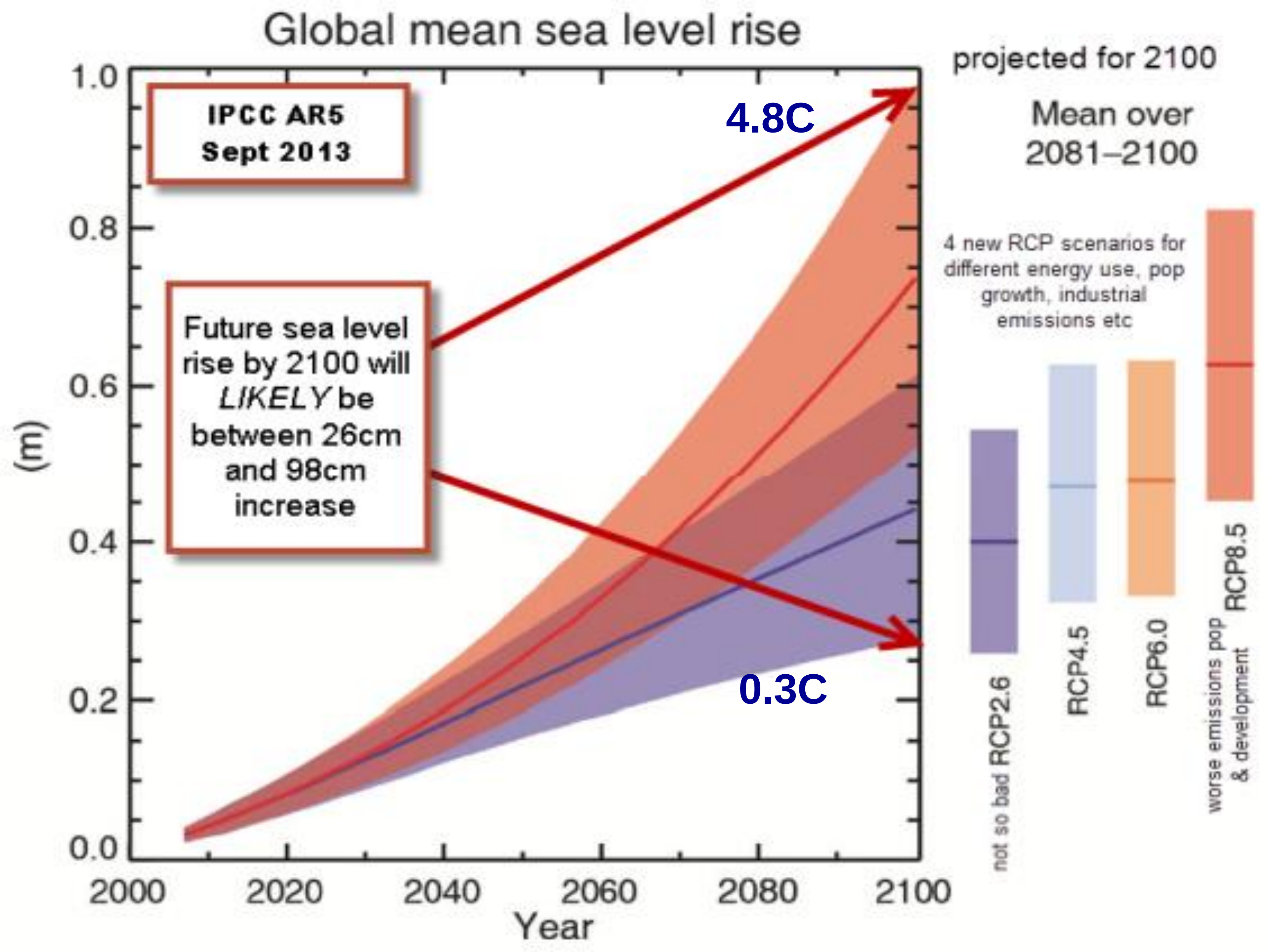


"Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global mean sea level rise (high confidence). Over the period 1993 to 2010, global mean sea level rise is, with high confidence, consistent with the sum of the observed contributions from ocean thermal expansion due to warming (1.1 [0.8 to 1.4] mm yr–1), from changes in glaciers (0.76 [0.39 to 1.13] mm yr–1), Greenland ice sheet (0.33 [0.25 to 0.41] mm yr–1), Antarctic ice sheet (0.27 [0.16 to 0.38] mm yr–1), and land water storage (0.38 [0.26 to 0.49] mm yr–1). The sum of these contributions is 2.8 [2.3 to 3.4] mm yr–1" IPCC AR5 2013

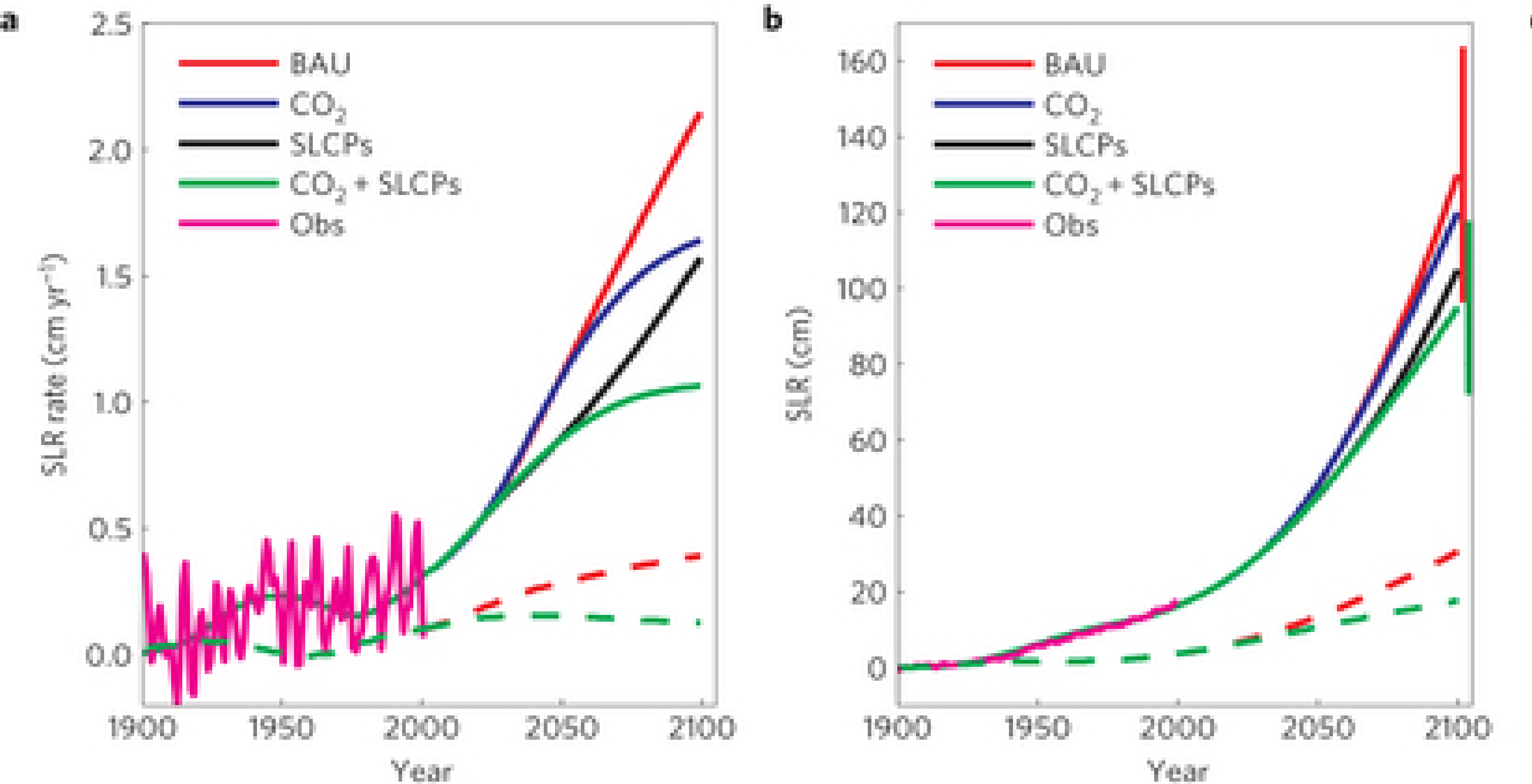
Sea Level Rise Budget in 2013

Ocean Warming	1.1 mm/yr (0.8-1.4)
Glaciers	0.76 mm/yr (0.39-1.13)
Land Water	0.38 mm/yr (0.26-0.49)
Greenland	0.33 mm/yr (0.25-0.41)
Antarctic	0.27 mm/yr (0.16-0.38)
Sum	2.8 mm/yr (2.3-3.4)
Average in Satellite era	3.2 mm yr–1 (2.8- 3.6)

1mm/yr = 10 cm/century


Global mean sea level rise
IPCC AR5
Sept 2013
Future sea level rise by 2100 will *LIKELY* be between 26cm and 98cm increase
4.8C
0.3C
1.0
0.8
0.6
0.4
0.2
0.0
(m)
2000
2020
2040
2060
2080
2100
Year
projected for 2100
Mean over 2081–2100
4 new RCP scenarios for different energy use, pop growth, industrial emissions etc
not so bad RCP2.6
RCP4.5
RCP6.0
RCP8.5
worse emissions pop & development

Short Term Slowing Of Sea Level Rise

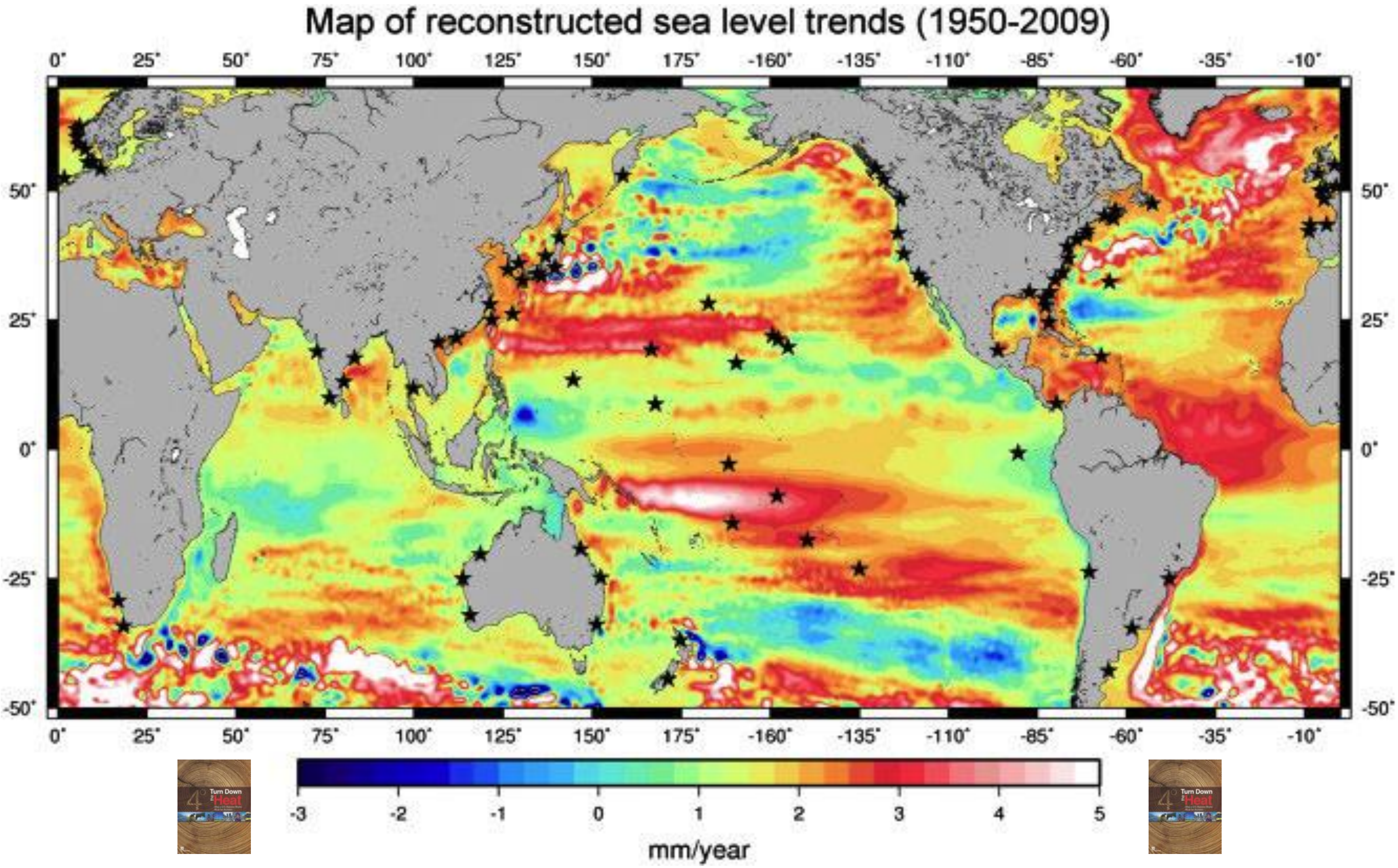


Hu, *et al*, Mitigation of short-lived climate pollutants slows sea-level rise, Nature Climate Change 3, 730–734 (2013)

Sea Level Rise

Regional Variation
Populations at Risk
Storm Surges
Salt Water Intrusion

Regional Sea Level Rise



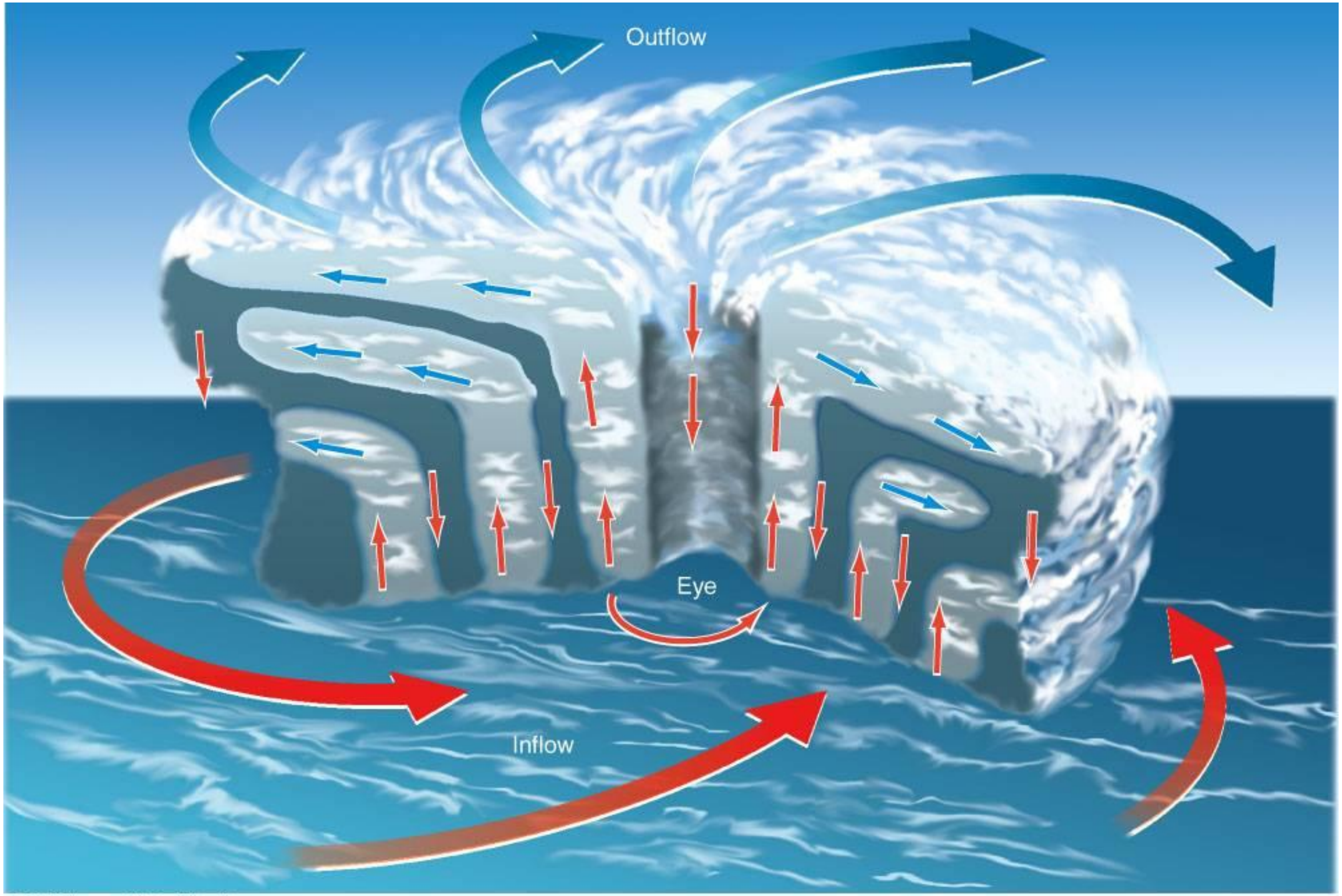
Regional SLR + local subsidence is what matters to people, coastal ecosystems

El Nino, Malibu,1997

El Nino **cycle initiated by warm surface waters in Western Pacific**

Hurricanes, Cyclones,Typhoons

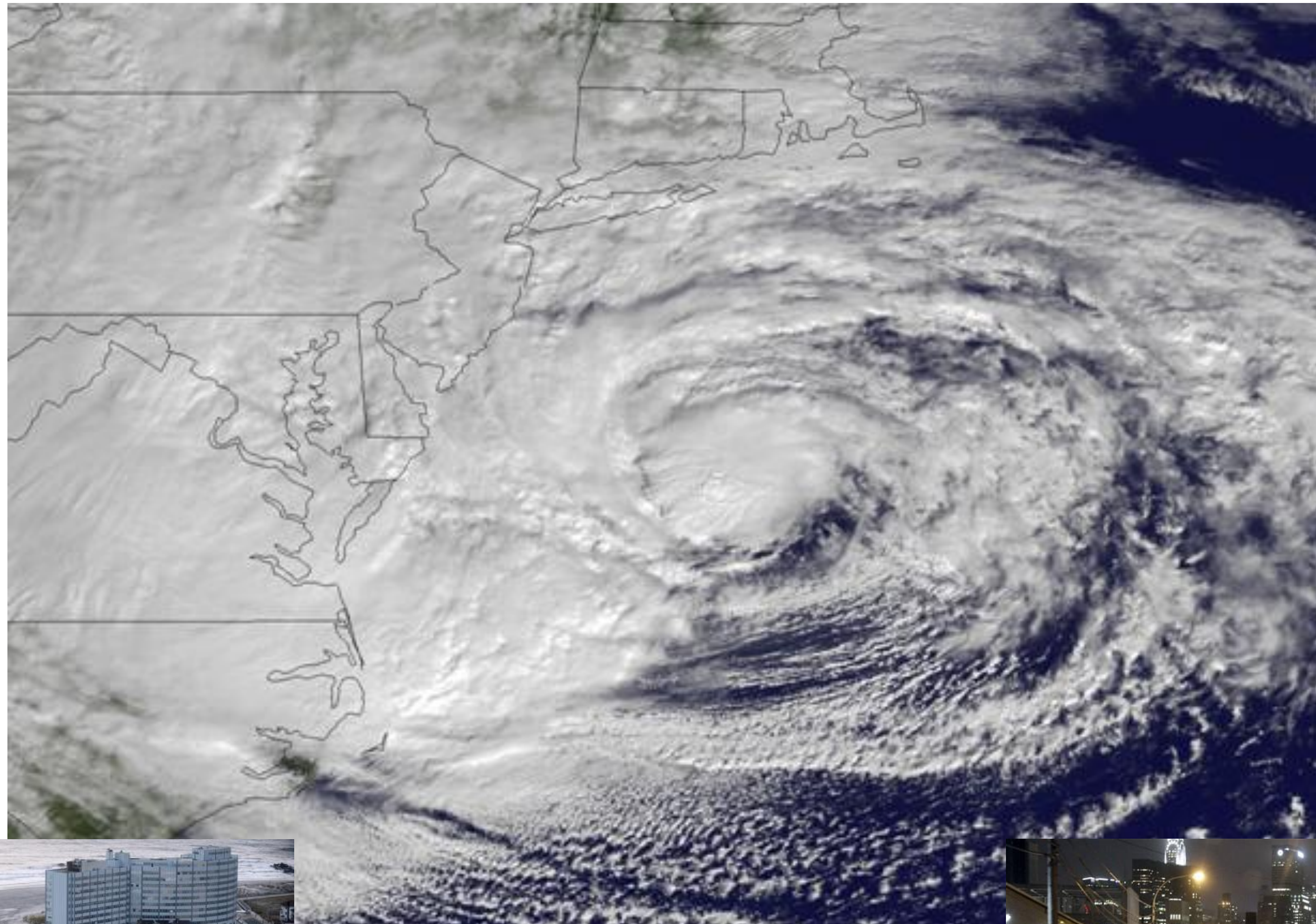
Generated when local Sea Surface Temperature exceeds 27C



Size and strength of storm depends on area and depth of warm water

Superstorm Sandy, 2012

$68 B damages, 286 dead



Frequency of Sandy-like events increases 2-7 times for each 1C increase in temperature,

Grinsted, A., *et. al., PNAS, 110, 14,* 5369-5373, April 2013

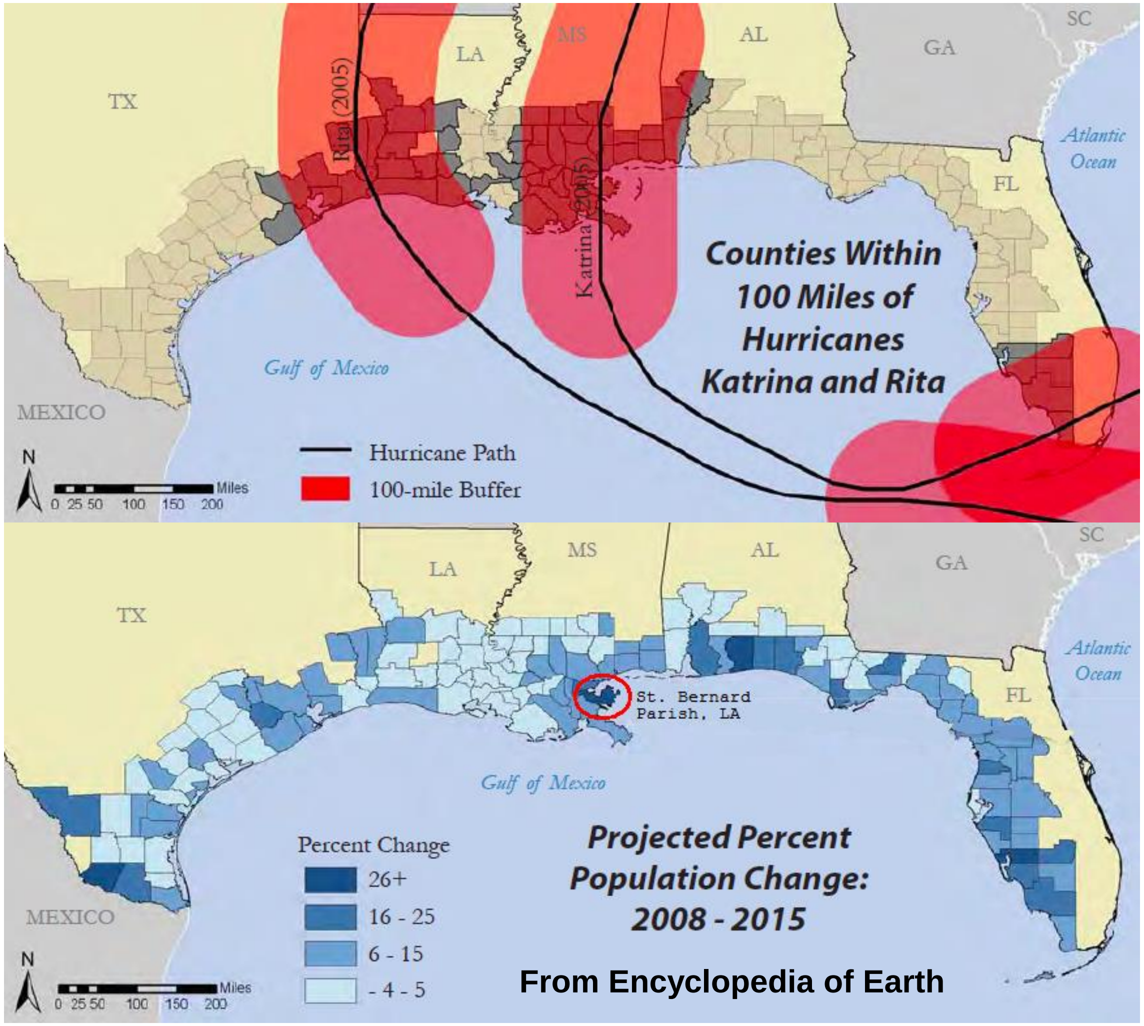
No Clear Trend

IPCC AR5, Chapter 3, 2013

“There is *low confidence* of any trend or long term change in tropical or extra-tropic storm frequency or intensity in any ocean basin, although there is robust evidence for an increase in the most intense tropical cyclones in the North Atlantic basin since the 1970s.

More People At Risk

A Global Trend



In 2010, 39 percent of the US population lived in coastal shoreline counties (<10% of the total land area excluding Alaska). The coastal population density is over six times greater than the corresponding inland counties. NOAA, 2013.

Low-Lying Island Nations

Facing existential threat, they are already considering wholesale moves to mainland

Maldives, N Indian Ocean

Kiribati, NW Pacific Ocean

Intrusion Before Inundation

Saltwater Intrusion Destroys Crops

Taro crops destroyed by encroaching saltwater at Lukunoch Atoll, Chuuk State, FSM. Giant swamp taro, a staple crop in Micronesia, has a two- to three-year growing period. After a saltwater inundation from a storm surge or very high tide, it may take two years of normal rainfall to flush the brackish water, resulting in a five-year gap before the next harvest if no further saltwater intrusion takes place.
Photo:John Quidachay/USDA Forest Service.

Nile Delta

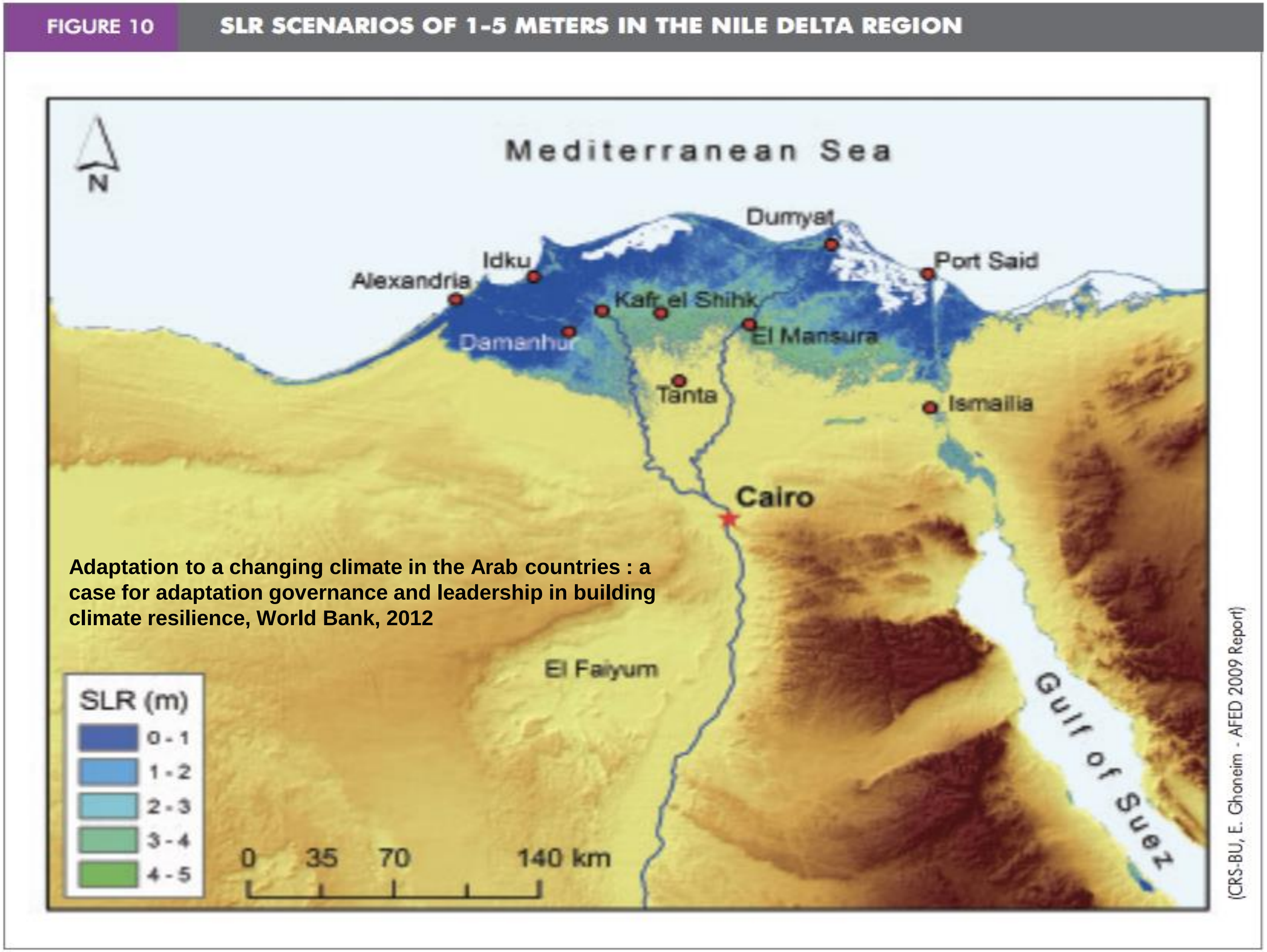
37% of Egypt's population

Some of the most fertile agricultural land in the world

Courtesy, NASA Astronaut Douglas Wheelock

Nile Delta

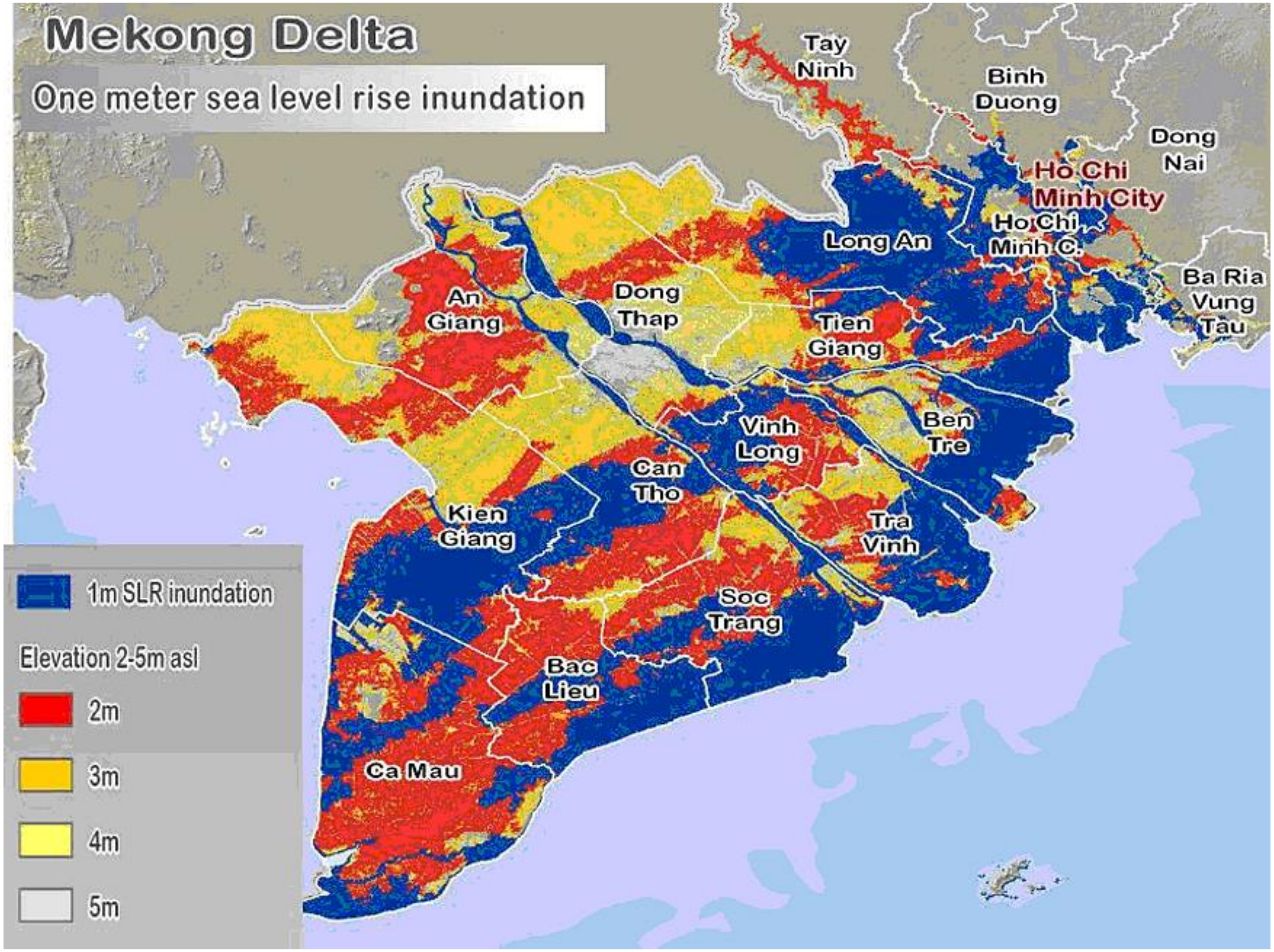
Salt water intrusion a major worry for agriculture when local relative SLR reaches 1 m



Adaptation to a changing climate in the Arab countries : a case for adaptation governance and leadership in building climate resilience, World Bank, 2012

Mekong Delta

Vietnam's most productive agricultural region



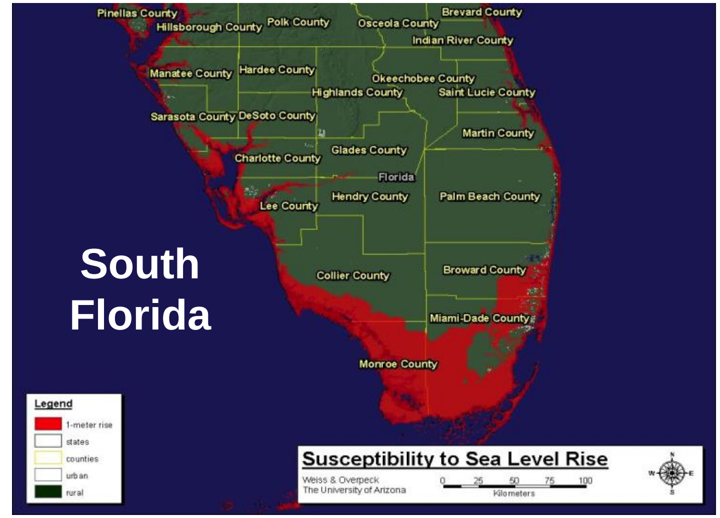
The Climate Change Research Institute at Can Tho University has predicted that many provinces in the Mekong Delta will be flooded by 2030.

Vulnerability Assessment

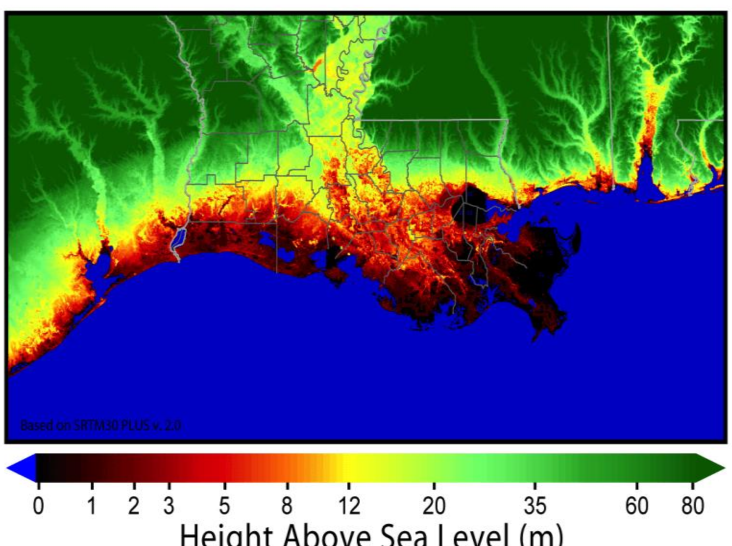
Demographic, economic, ecological, and urban spatial data combined with Digital Elevation Maps

Vulnerable U.S. Regions

1-2 m Relative Sea Level Rise



Sea Level Risks - Louisiana



OECD's Top Six

#1: Miami
4.8M. $3.5T

#2: Guangzhou
2.7M, $3.4T

#3: New York-Newark
2.9M, $2.1T

#4: Kolkata
14.0M, $2.0T

#5: Shanghai
5.5M, $1.8T

#6: Mumbai
11.4M, $1.6T

Nicholls, R.J., *et. al.,* Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates, OECD, 2007,

Sea Level Rise

Adaptation

The Venice Conference

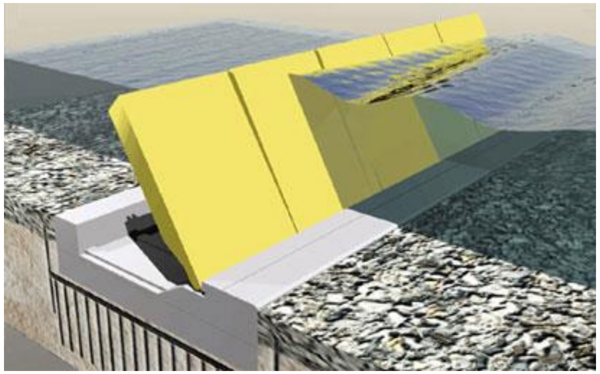
Improving the capacity to assess and adapt to climate change

Venice, Sept 12-15, 2011

Venice

Iconic Historical city

MOSE Gates



Tokyo Bay

640,000 below sea level

Comprehensive Plan

London

"Pool of London"

Thames River Barrages

The Netherlands

One of the world's most densely populated regions is near or below sea level

A 500-year tradition of fighting the sea

A 100-year, $1/4T, commitment to strengthen all coastal defenses

Venice's Protector: Its Lagoon

From military security then to environmental security today

Magistrato Alle Acque founded in 1505

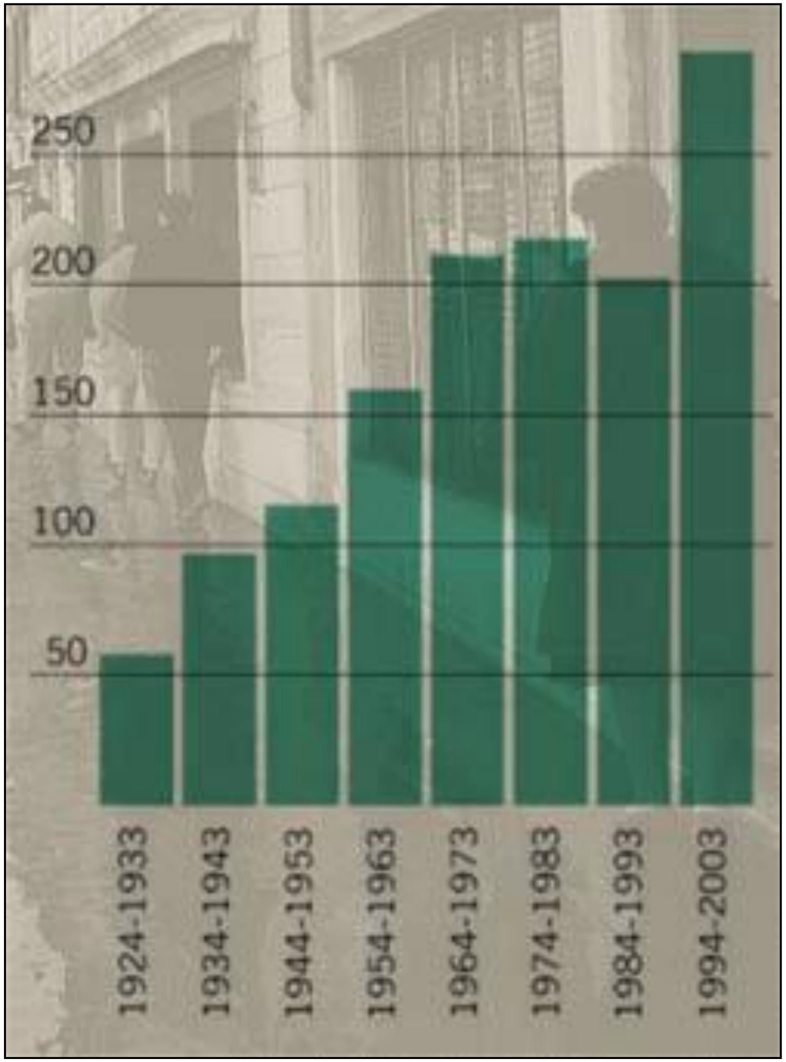
Water too deep: Big warships enter lagoon

Water too shallow: Troops march in

Venice

The poster child for sea level rise without ever meaning to be

Frequency of flooding events (>60 cm), the "Acqua Alta",
started increasing before climate change was a prominent issue



Venice's Recurring Nightmare

Storm surges driven by Sirocco winds during a November king tide

Acqua Alta, November 2012

MOSE

The largest single environmental project in Europe

6B Euros

Proposed 1970s
Study completed 1981
Conceptual design 1989
Environmental impact study 1997
Final design 2002
Work started 2003
Completion in 2016

How long can MOSE protect Venice?

12 cm land subsidence + 13 centimeters sea level rise = 25 cm relative SLR in the past century

Subsidence thought to be abating since withdrawals of underground water and gas stopped in the 1970s

Relative SLR between 17 and 53 cm by 2100

L. Carbonin, et. al., Clim Dyn (2010) 35:1039–1047DOI 10.1007/s00382-009-0617-5

80 cm RSLR would close the gates 346 times/yr

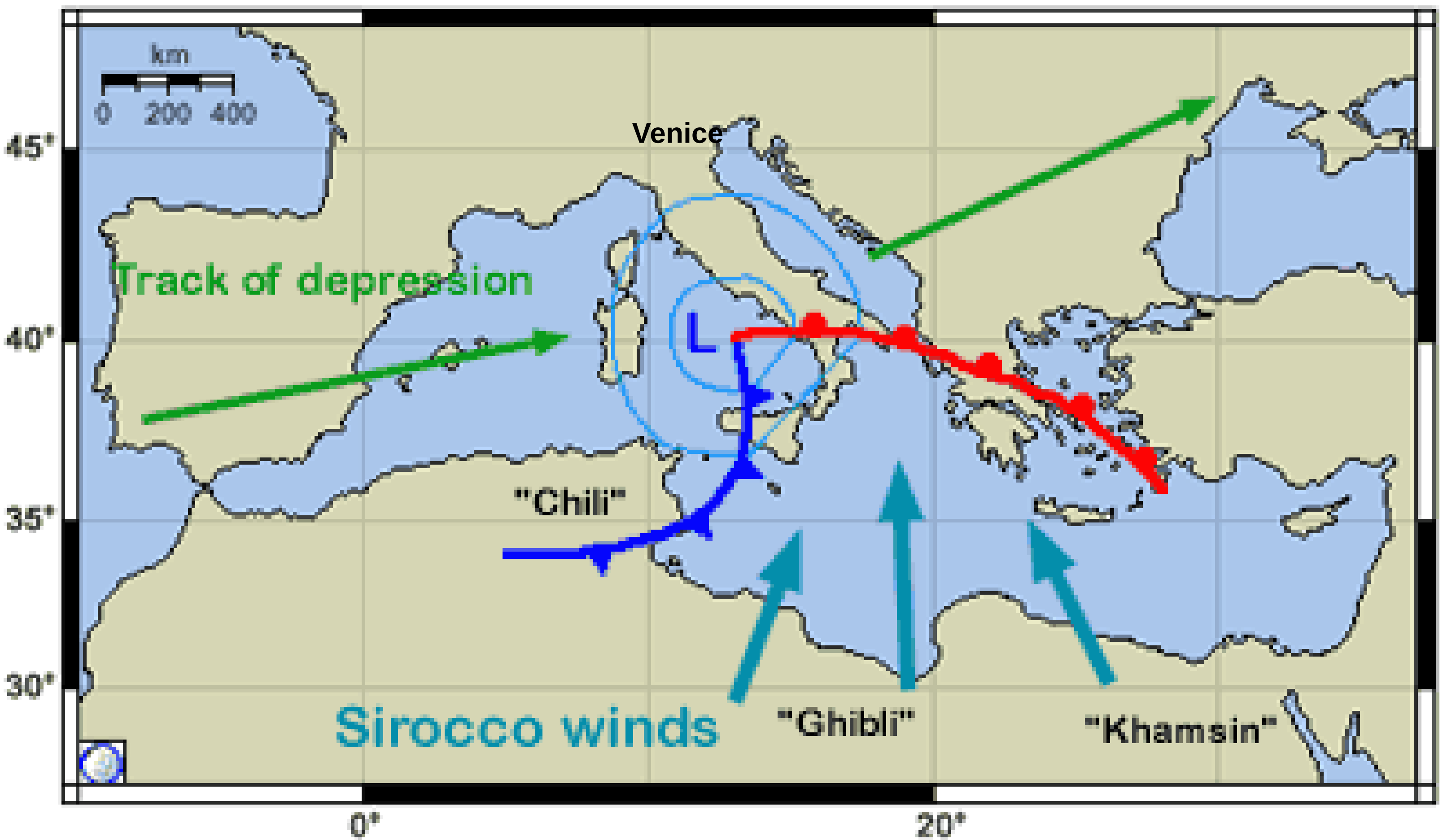
S. Iacobellis and D. Cayan, 2012

Sirocco

60 Mph Winds for up to 36 hours

Peak occurrence in March and November

November Sirocco conspires with astronomical king tide



Extreme Water Level Events at Venice during the 21st Century

S.F. Iacobellis and D.R. Cayan
SIO/SSI

Used IPCC AR4 2007 climate models for the Adriatic to estimate number of times Sirocco blows for 2 days, combined with astronomical tide data, and SLR scenarios

Gates will be closed 346 times per year when local relative mean sea level has increased by 80 cm.

When will that take place?

Unknowns include Greenland and Antarctica mass loss rates, changes in local Adriatic SLR and subsidence rates

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THETIS

knowledge
for a better
environment

UC San Diego

Local Impact, National Influence, Global Reach

Sustainable Management of Venice Lagoon Facing Climate Change

Analysis of best practices

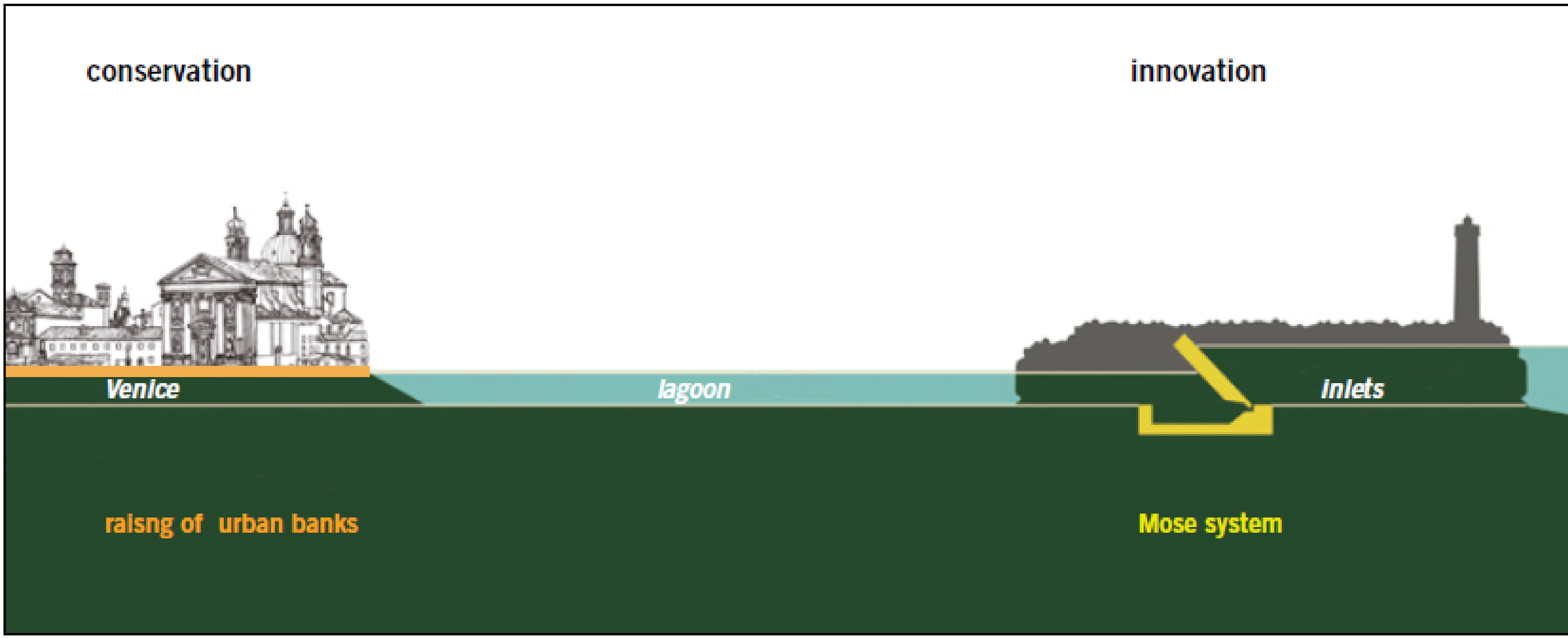
E. Ramieri, C. Cerasuolo, E. Delaney, M. Neidhardt, F. Turco

Thetis

A state of the art sustainability management plan!

Adaptive Management

Climate, Environmental, Economic, Social Change



Ocean, Ecological, and Civil Engineering

Raise low-lying parts of city *and* hold off *Aqua Alta*

Ecotoxicology of sediments

Interrelationships between circulation and ecology

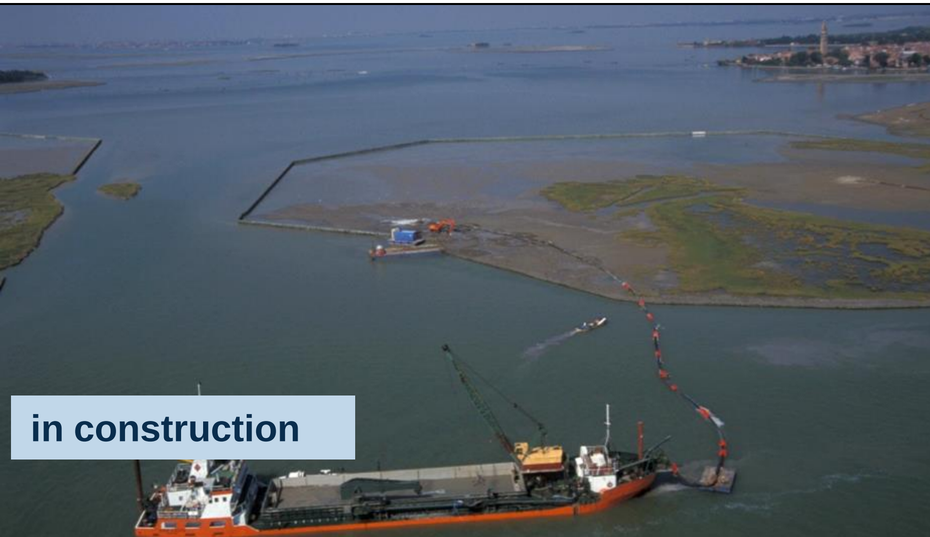
Ecological restoration to increase resilience

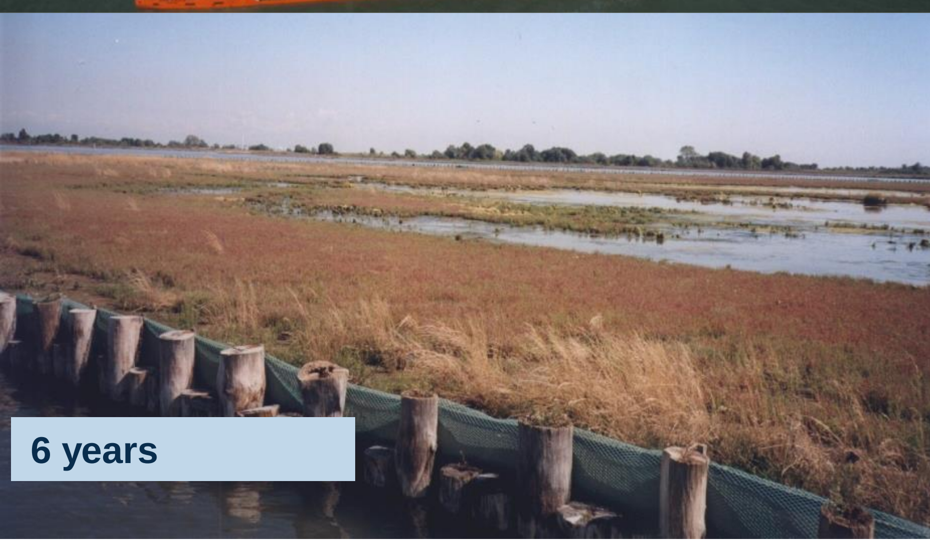
New salt marshes to break up wind-wave interactions

Strengthen urban waste disposal systems

Operate gates to flush pollution from City and Lagoon

New Salt Marshes





Best Practice Consortia: Coastal Cities and Ecosystems

Global (13)	Europe (5)
C40 Cities Climate Leadership Group	International Network for Storm Surge Barrier Managers
Climate Neutral Network	Climate-KIC
The Climate and Development Knowledge Network	European Network of Heads of Nature Conservation Agencies
Climate Action Network	SIC adapt!
Association of Pacific Rim Universities World Initiative	Climate Alliance
Global Facility for Disaster Reduction and Recovery	**North America (3)**
The Urban Climate Change Research Network	The Mayors Climate Protection Center
ICLEI - Local Governments for Sustainability	Clean air Partnership
Sustainable Urban Development Network	Transatlantic Cities Network
Climate Change Adaptation and Development Initiative	
Connecting Delta Cities	**Asian (2)**
Delta Alliance	Asian Cities Climate Change Resilience Network
Global Water Partnership	Asia and the Pacific Adaptation Network

Oceania (2)	Africa (1)
The Marine Adaptation Network	The Adaptation Network
Social Science Climate Change Research Network	

Sea level rise is unstoppable and will continue for a thousand years

Millions of people and trillions of infrastructure dollars are at risk today and at increasing risk tomorrow

Coastal cities around the world have begun to prepare for sea level rise

There is a convergence of views on best practices for assessing impacts of climate change and sea level rise

A few cities have action plans

Even fewer have sustainable management strategies

Venice is in the vanguard

Knowledge Flirting with Action

Were these workshops the diversions of a handful of academics and decision makers with time on their hands?

Will the glow of their happy talk inevitably fade into the darkness of night?

Or did we just catch a glimpse of the first faltering steps in a dance between global knowledge and local action that is destined to go on and on until the darkness Is lifted at last?